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QUADZILLA

NATIONAL LINEAR QUAD APPLICATION BOOK



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What Benefit Do You Attribute To Linear IC's? It could be reduced cost and complexity or a previously unachieved performance. The rate of growth of the IC industry has been due to both, but the growth has been so great that it has been hard to see the forest for the trees. New and exotic devices are constantly being introduced, but what trends are emerging?

The growth of technology has led the user to expect more complex or more accurate devices, but two new trends have emerged very quietly. First is the trend towards simplified "Functional Blocks". These are devices that are very simple to use and have multiple uses, and second is the trend to multiple devices.

Looking back in history, the idea is not new, the digital world did this years ago. Nobody today buys one gate, they buy an IC with several gates or combinations of devices in them. The reasons are many, but the major ones are:

1. They cost less than purchased individually
2. More reliable than individual parts
3. Less handling cost
4. Less board space
5. More flexibility

Getting back to the concept of "functional block" you see the application literature chock full of circuits such as Voltage Controlled Oscillators, up-down staircase generator, time delays, limit comparators, and so on, all made with quads containing amplifiers or comparators. Here is a new concept of not only using the advantages shown for the digital world, but the ability to use simple quad linear devices to build more complex circuits.

While the design problem has been simplified, other benefits have been added. First is that the devices presently available only require one power supply. The elimination of a negative supply in a system can lead to great savings. Secondly, these devices operate over a wide range of power supply voltages and consume very little power, opening up the use in battery operated equipment.

The result is a quiet trend towards circuit and system simplification through the use of new quad devices using the industries latest technologies.

Which Quad is Best? Each of National's Quads offers unique advantages for a particular situation. The best quad to use for a given application can be determined by considering the basic differences between them. The first consideration is whether to use an op amp or a comparator. Comparators are usually associated with digital, or ON-OFF applications and are not intended to be used in place of an op amp as a gain block in linear feedback amplifiers. Thus with comparators, like the LM339 there is no concern for closed-loop stability factors such as the gain margin or phase margin specs which are associated with an op amp. However, the input specs of comparators: input bias current, input offset current—the difference between the input bias currents of the (+) and (-) inputs—and offset voltage are the same basic parameters as those specified for op amps.

There is one slight benefit in employing a comparator; the input offset voltage is not degraded by the closed loop gain as with an op amp. Errors due to input offset voltage are calculated based upon the percentage of the reference voltage. A 2mV offset voltage therefore represents only a 0.1% error if the reference voltage is 2Vdc. For improved accuracy when working with low level reference voltages, and for reduced temperature drift of the offset voltage, a special LM339A precision comparator product is available where all four comparators are guaranteed to have an offset voltage of less than 2mV.

The fact that comparators are not designed for use in linear feedback applications means that the frequency compensation capacitor, which is essential for an op amp, can be omitted. This allows the comparator to change output voltage states more rapidly than an op amp—there is no longer a need to charge and discharge the compensation capacitor which limits the slew rate of an op amp. As a result, comparators can replace op amps in many standard non-linear (ON-OFF) op amp application circuits and will operate at higher frequencies. This improvement is easily seen in high frequency square wave oscillators, narrow pulse generators and crystal oscillators where the relatively slow slew rate of an op amp is most aggravating.

Finally, the output stage of a comparator is usually designed to either source or sink current. Op amps will do both and for some applications this can be a problem. For example, comparators can be used to provide an electronically controlled single-pole single-through switch to ground and can usually allow outputs to directly tie together to provide a logical OR'ing of two input functions.

Op amps are the most versatile linear product as they can be used as both linear and non-linear feedback amplifiers and can also be operated open loop for high gain comparator applications. But they do suffer in response time because of the frequency compensation capacitor. The largest benefit of the op amp is the predictability of the linear closed-loop characteristics which are derived from the use of negative feedback.

The LM324 op amp operates in a conventional manner—the output voltage responds to a differential input voltage, and offers many application advantages in single power supply systems. The new operating feature of most significance is the fact that the input common-mode voltage range includes ground and the output voltage can swing to ground, even when powered by a single power supply. This, in addition to the wide operating range of power supply voltage (3 to 30Vdc), will obsolete the requirement for the standard $\pm 15\text{Vdc}$ power supplies for many linear systems—the +5Vdc supply which is used with most logic circuits is adequate for many applications. Finally, the low power supply current drain makes the LM324 a useful product for battery powered equipment or CMOS systems.

The LM3900 "Norton Amp," or current-differencing amplifier, represents a new way to build an op amp. This is a very non-conventional circuit which, again, offers many application advantages in single power supply systems. Performance as a DC amplifier is not as precise as the LM324, but is adequate in many less critical applications. Many new and novel circuits are made possible by the "current-mirror" which is used at the non-inverting input. Waveform generators can be more easily realized with the Norton op amp and a wide range of useful functions can be economically achieved with this product.

A more detailed analysis of these quads can be obtained by comparing the performance characteristics which are listed on the individual data sheets which are included in this booklet. In addition, many application circuits are presented both on the data sheets and in separate, rather complete, application notes which are available for each product. These can be obtained from your National representative. See the back page for the address of the one nearest to you.



LM124/LM224/LM324 quad op amps

general description

The LM124 series consists of four independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM124 series can be directly operated off of the standard +5V_{DC} power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional $\pm 15\text{V}_{\text{DC}}$ power supplies.

unique characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

advantages

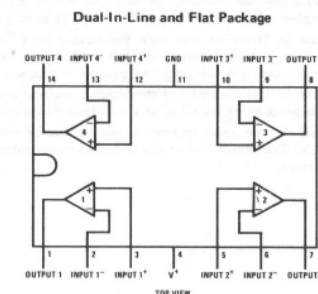
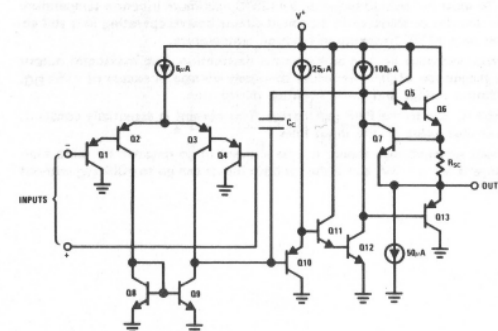
- Eliminates need for dual supplies

- Four internally compensated op amps in a single package
- Allows directly sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

features

- Internally frequency compensated for unity gain
- Large DC voltage gain 100 dB
- Wide bandwidth (unity gain) 1 MHz (temperature compensated)
- Wide power supply range:
Single supply 3V_{DC} to 30V_{DC}
or dual supplies $\pm 1.5\text{V}_{\text{DC}}$ to $\pm 15\text{V}_{\text{DC}}$
- Very low supply current drain (800 μA) — essentially independent of supply voltage (1 mW/op amp at +5V_{DC})
- Low input biasing current 45 nA_{DC} (temperature compensated)
- Low input offset voltage 2 mV_{DC} and offset current 5 nA_{DC}
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage 0V_{DC} to V⁺ - 1.5V_{DC} swing

schematic and connection diagrams



absolute maximum ratings

Supply Voltage, V^+	$32 V_{DC}$ or $\pm 16 V_{DC}$
Differential Input Voltage	$32 V_{DC}$
Input Voltage	$-0.3 V_{DC}$ to $+32 V_{DC}$
Power Dissipation (Note 1)	
Molded DIP (LM324N)	570 mW
Cavity DIP (LM124D, LM224D & LM324D)	900 mW
Flat Pack (LM124F)	800 mW
Output Short-Circuit to GND (Note 2)	Continuous
$V^+ \leq 15 V_{DC}$ and $T_A = 25^\circ C$	
Operating Temperature Range	
LM324	$0^\circ C$ to $+70^\circ C$
LM224	$-25^\circ C$ to $+85^\circ C$
LM124	$-55^\circ C$ to $+125^\circ C$
Storage Temperature Range	$-65^\circ C$ to $+150^\circ C$
Lead Temperature (Soldering, 60 sec)	$300^\circ C$

electrical characteristics ($V^+ = +5 V_{DC}$ and $T_A = 25^\circ C$ unless otherwise noted)

PARAMETER	CONDITIONS	LM124			LM224, LM324			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	$R_B = 0\Omega$	2	5		2	7		mV _{DC}
Input Bias Current (Note 3)	$I_{IN(+)} \text{ or } I_{IN(-)}$	45	300		45	500		nA _{DC}
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$	± 3	± 30		± 5	± 50		nA _{DC}
Input Common-Mode Voltage Range (Note 4)		0	$V^+ - 1.5$		0	$V^+ - 1.5$		V _{DC}
Supply Current	$R_L = \infty$ On All Op Amps	0.8	2		0.8	2		mA _{DC}
Large Signal Voltage Gain	$R_L \geq 2 k\Omega$	100			100			V/mV
Output Voltage Swing	$R_L = 2 k\Omega$	0	$V^+ - 1.5$		0	$V^+ - 1.5$		V _{DC}
Common Mode Rejection Ratio	DC	85			85			dB
Power Supply Rejection Ratio	DC	100			100			dB
Amplifier-to-Amplifier Coupling	$f = 1 \text{ kHz}$ to 20 kHz (Input Referred)	-120			-120			dB
Output Current Source	$V_{IN}^+ = +1 V_{DC}$, $V_{IN}^- = 0 V_{DC}$	20	40		20	40		mA _{DC}
Output Current Sink	$V_{IN}^- = +1 V_{DC}$, $V_{IN}^+ = 0 V_{DC}$	10	20		10	20		mA _{DC}

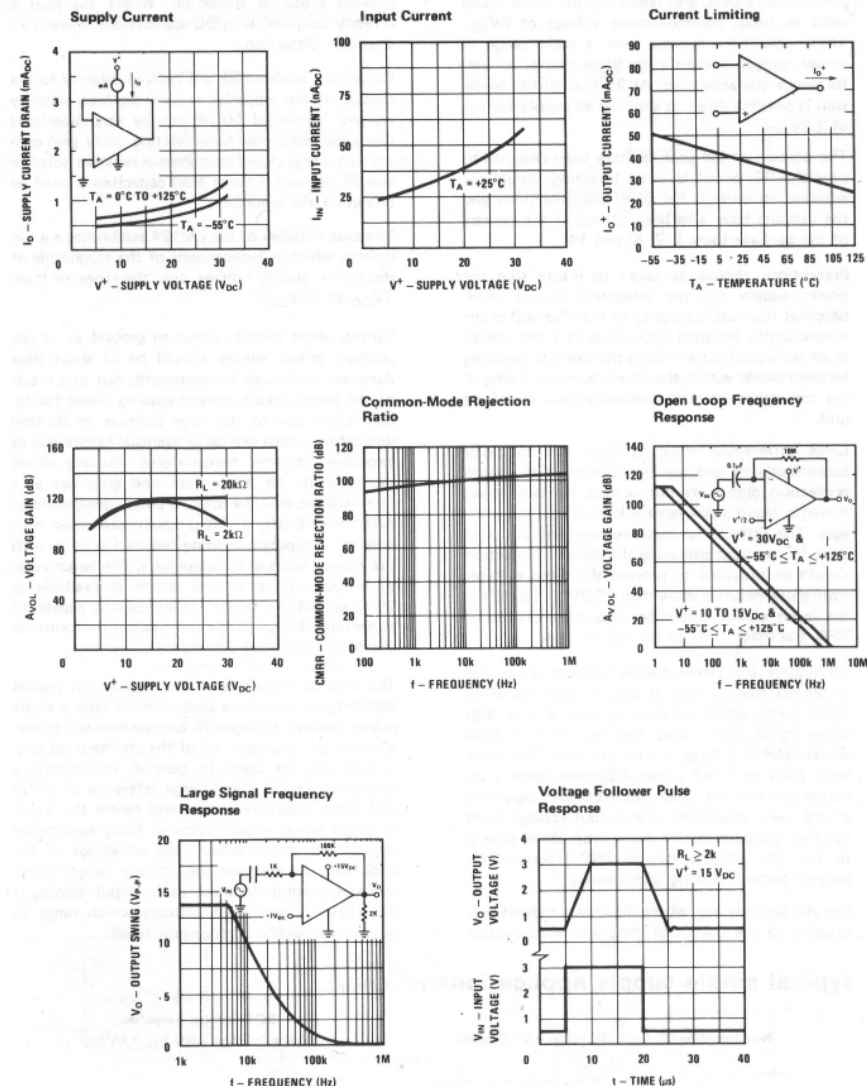
Note 1: For operating at high temperatures, the LM324 must be derated based on a $+125^\circ C$ maximum junction temperature and a thermal resistance of $175^\circ C/W$ which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM224 and LM124 can be derated based on a $+150^\circ C$ maximum junction temperature.

Note 2: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. The maximum output current is approximately 40 mA independent of the magnitude of V^+ . At values of supply voltage in excess of $+15V_{DC}$, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction.

Note 3: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 4: The input common-mode voltage or either input signal voltage should not be allowed to go negative by more than 0.3V. The upper end of the common-mode voltage range is $V^+ - 1.5V$, but either or both inputs can go to $+30V_{DC}$ without damage.

typical performance characteristics



application hints

The LM124 series are op amps which operate with only a single power supply voltage, have true differential inputs, and remain in the linear mode with an input common-mode voltage of $0V_{DC}$. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At $25^{\circ}C$ amplifier operation is possible down to a minimum supply voltage of $2.3V_{DC}$.

The pinouts of the package have been designed to simplify PC board layouts. Inverting inputs are adjacent to outputs for all of the amplifiers and the outputs have also been placed at the corners of the package (pins 1, 7, 8, and 14).

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accommodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than $-0.3V_{DC}$ (at $25^{\circ}C$). An input clamp consisting of a diode-connected NPN transistor (C-B short) can be used.

To reduce the power supply current drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For AC applications, where the load is capacitively coupled to the output of the amplifier, a resistor

should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in DC applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accommodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

The bias network of the LM124 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from $3V_{DC}$ to $30V_{DC}$.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at $25^{\circ}C$ provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

typical single-supply applications (con't) ($V^+ = 5V_{DC}$)

High Input Z, DC Differential Amplifier

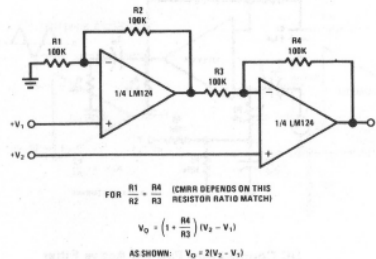
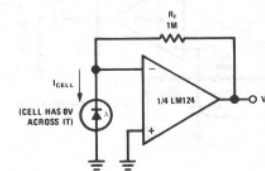
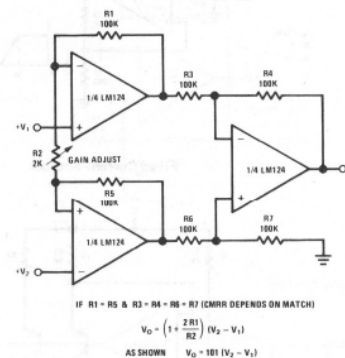


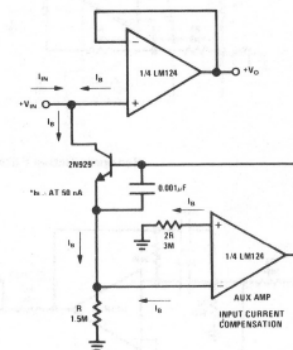
Photo Voltaic-Cell Amplifier



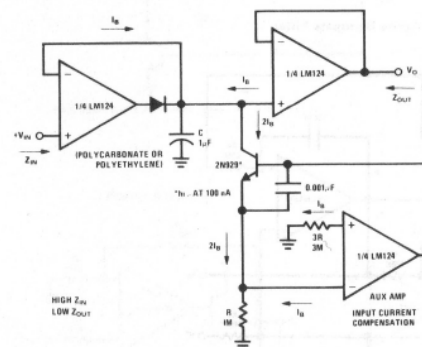
High Input Z Adjustable-Gain DC Instrumentation Amplifier



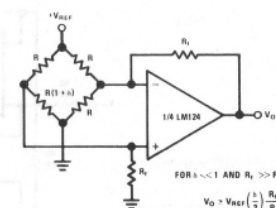
Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



Low Drift Peak Detector

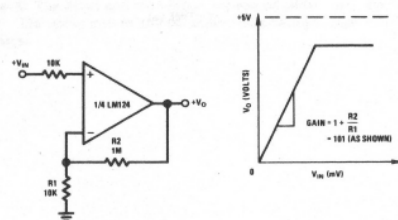


Bridge Current Amplifier

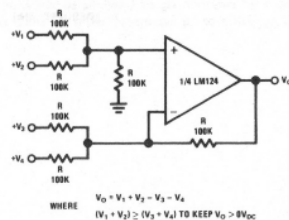


typical single-supply applications ($V^+ = 5V_{DC}$)

Non-Inverting DC Gain ($0V$ Input = $0V$ Output)

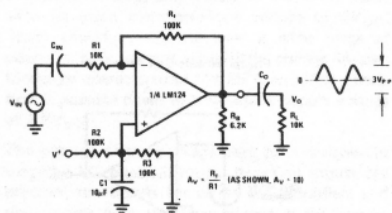


DC Summing Amplifier ($V_{IN}'S \geq 0V_{DC}$ AND $V_0 \geq 0V_{DC}$)

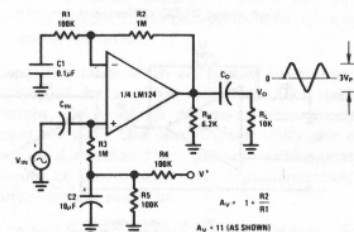


typical single-supply applications (con't) ($V^+ = 5V_{DC}$)

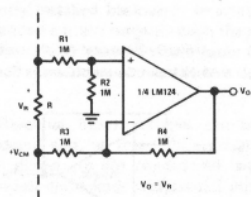
AC Coupled Inverting Amplifier



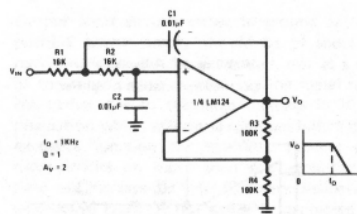
AC Coupled Non-Inverting Amplifier



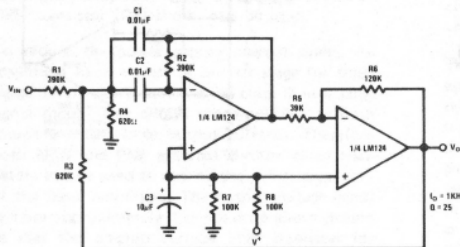
Ground Referencing A Differential Input Signal



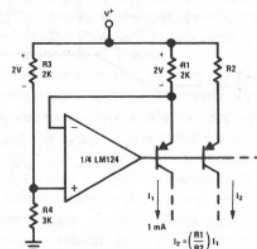
DC Coupled Low-Pass RC Active Filter



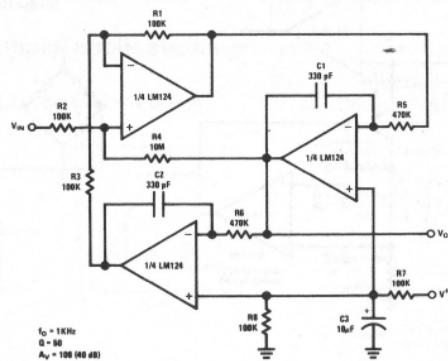
Bandpass Active Filter



Fixed Current Sources

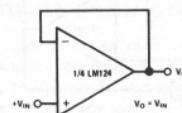


"BI-QUAD" RC Active Bandpass Filter

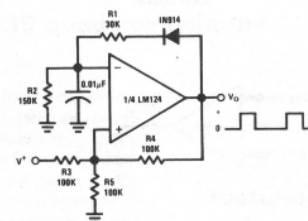


typical single-supply applications (con't) ($V^+ = 5V_{DC}$)

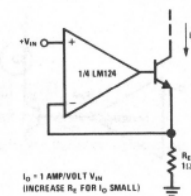
Voltage Follower



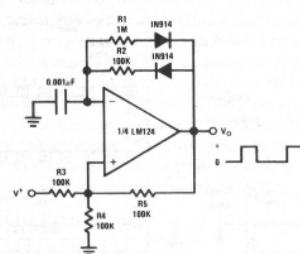
Pulse Generator



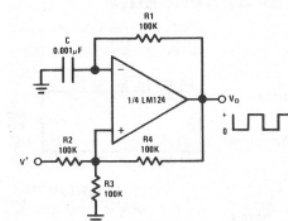
High Compliance Current Sink



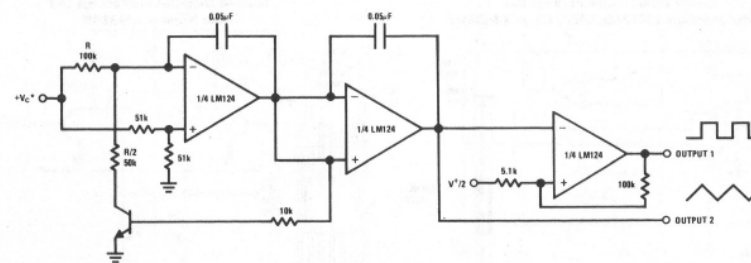
Pulse Generator



Squarewave Oscillator

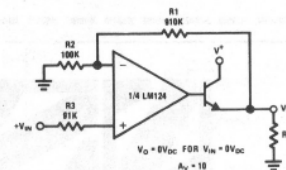


Voltage Controlled Oscillator (VCO)

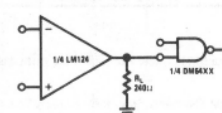


*WIDE CONTROL VOLTAGE RANGE: $0 V_{DC} \leq V_{in} \leq 2(V^+ - 1.5 V_{DC})$

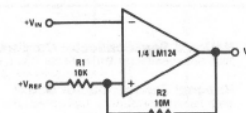
Power Amplifier



Driving TTL

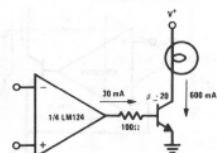


Comparator With Hysteresis

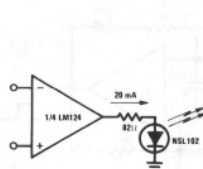


typical single-supply applications (con't) ($V^+ = 5V_{DC}$)

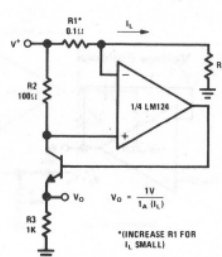
Lamp Driver



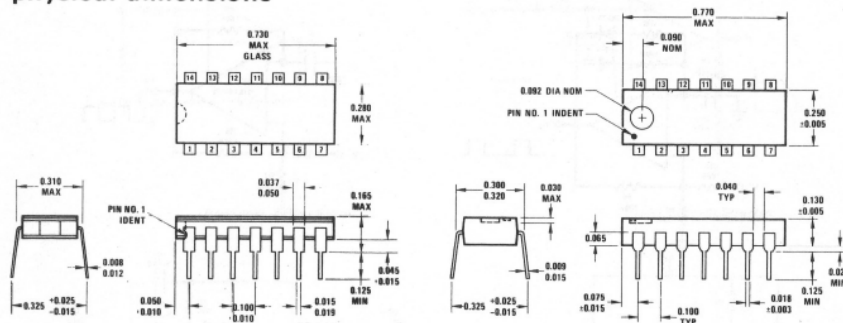
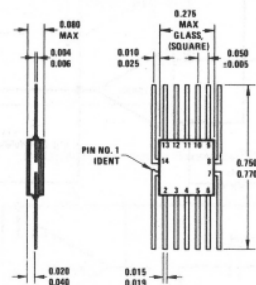
LED Driver



Current Monitor



physical dimensions

Cavity Dual-In-Line Package (D)
Order Numbers LM124D, LM224D, or LM324DMolded Dual-In-Line Package (N)
Order Number LM324NFlat Package (F)
Order Number LM124F

Manufactured under one or more of the following U.S. patents: 3082052, 3180758, 3231787, 3203256, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440498, 3518750, 3519887, 3557431, 3560765, 3566218, 3571630, 3575808, 3579809, 3593069, 3597640, 3607469, 3617859, 3631312, 3633052, 3638131, 3648071, 3651565, 3653248.

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LM139/LM239/LM339 quad comparators

general description

The LM139 series consists of four independent voltage comparators which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage. These comparators also have a unique characteristic in that the input common-mode voltage range includes ground, even though operated from a single power supply voltage.

Application areas include limit comparators, simple analog to digital converters; pulse, squarewave and time delay generators; wide range VCO; MOS clock timers; multivibrators and high voltage digital logic gates. The LM139 series was designed to directly interface with TTL and CMOS. When operated from both plus and minus power supplies, the LM339 will directly interface with MOS logic — where the low power drain of the LM339 is a distinct advantage over standard comparators.

advantages

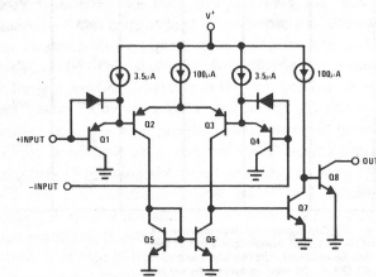
- Eliminates need for dual supplies

- Allows sensing near GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

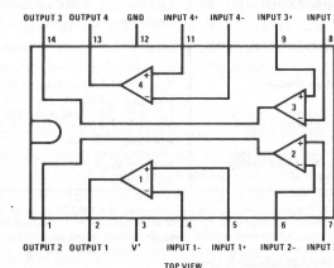
features

- Wide single supply Voltage range
or dual supplies $2V_{DC}$ to $36V_{DC}$
 $\pm 1V_{DC}$ to $\pm 18V_{DC}$
- Very low supply current drain (0.8 mA) — independent of supply voltage (1 mW/comparator at $+5V_{DC}$)
- Low input biasing current 35 nA
- Low input offset current 3 nA
- and offset voltage 3 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Low output saturation voltage 1 mV at $5\mu A$
70 mV at 1 mA
- Output voltage compatible with TTL (fanout of 2), DTL, ECL, MOS and CMOS logic systems

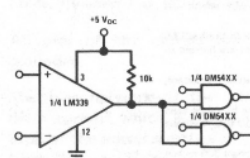
schematic and connection diagrams



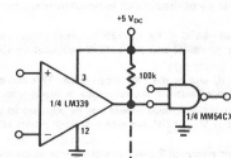
Dual-In-Line and Flat Package



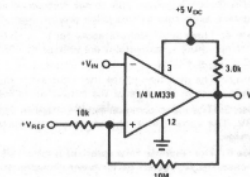
typical applications



Driving TTL



Driving CMOS



Comparator with Hysteresis

absolute maximum ratings

Supply Voltage, V^+	36 V_{DC} or $\pm 18 V_{DC}$	Input Current ($V_{IN} < -0.3 V_{DC}$) (Note 3)	50 mA
Differential Input Voltage	36 V_{DC}	Operating Temperature Range	
Input Voltage	$-0.3 V_{DC}$ to $+36 V_{DC}$	LM339	0°C to $+70^\circ\text{C}$
Power Dissipation (Note 1)		LM239	-25°C to $+85^\circ\text{C}$
Molded DIP (LM339N)	570 mW	LM139	-55°C to $+125^\circ\text{C}$
Cavity DIP (LM139D, LM239D & LM339D)	900 mW	Storage Temperature Range	-65°C to $+150^\circ\text{C}$
Flat Pack (LM139F)	800 mW	Lead Temperature (Soldering, 10 seconds)	300°C
Output Short-Circuit to GND (Note 2)	Continuous		

electrical characteristics ($V^+ = +5.0 V_{DC}$, see Note 4)

PARAMETER	CONDITIONS	LM139			LM239, LM339			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	At Output Switch Point, $V_O \approx 1.4 V_{DC}$, $V_{REF} = +1.4 V_{DC}$ and $R_S = 0\Omega$, $T_A = +25^\circ\text{C}$		± 2.0	± 5.0		± 2.0	± 5.0	mV $_{DC}$
Input Bias Current (Note 5)	$I_{IN(+)}$ or $I_{IN(-)}$ With Output in Linear Range, $T_A = +25^\circ\text{C}$		25	100		25	250	nA $_{DC}$
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $T_A = +25^\circ\text{C}$		± 3.0	± 25		± 5.0	± 50	nA $_{DC}$
Input Common-Mode Voltage Range (Note 6)	$T_A = +25^\circ\text{C}$	0		$V^+ - 1.5$	0		$V^+ - 1.5$	V_{DC}
Supply Current	$R_L = \infty$ On All Comparators, $T_A = +25^\circ\text{C}$		0.8	2.0		0.8	2.0	mA $_{DC}$
Voltage Gain	$R_L \geq 15 \text{ k}\Omega$, $T_A = +25^\circ\text{C}$		200			200		V/mV
Large Signal Response Time	$V_{IN} = \text{TTL Logic Swing}$, $V_{REF} = +1.4 V_{DC}$, $V_{RL} = 5.0 V_{DC}$ and $R_L = 5.1 \text{ k}\Omega$		300			300		ns
Response Time (Note 7)	$V_{RL} = 5.0 V_{DC}$ and $R_L = 5.1 \text{ k}\Omega$, $T_A = +25^\circ\text{C}$		1.3			1.3		μs
Output Sink Current	$V_{IN(+)} \geq +1.0 V_{DC}$, $V_{IN(-)} = 0$ and $V_O \leq +1.5 V_{DC}$, $T_A = +25^\circ\text{C}$	6	16		6	16		mA $_{DC}$
Saturation Voltage	$V_{IN(+)} \geq +1.0 V_{DC}$, $V_{IN(-)} = 0$ and $I_{SINK} \leq 4.0 \text{ mA}$, $T_A = +25^\circ\text{C}$		250	500		250	500	mV $_{DC}$
Output Leakage Current	$V_{IN(+)} \geq +1.0 V_{DC}$, $V_{IN(-)} = 0$ and $V_{OUT} = 5.0 V_{DC}$, $T_A = +25^\circ\text{C}$		0.1			0.1		nA $_{DC}$
Input Offset Voltage	At Output Switch Point, $V_O \approx 1.4 V_{DC}$, $V_{REF} = +1.4 V_{DC}$ and $R_S = 0\Omega$			9.0			9.0	mV $_{DC}$
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$		± 100			± 150		nA $_{DC}$
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$ With Output in Linear Range		300			400		nA $_{DC}$
Input Common-Mode Voltage Range		0		$V^+ - 2.0$	0		$V^+ - 2.0$	V_{DC}
Saturation Voltage	$V_{IN(+)} \geq +1.0 V_{DC}$, $V_{IN(-)} = 0$ and $I_{SINK} \leq 4.0 \text{ mA}$			700			700	mV $_{DC}$
Output Leakage Current	$V_{IN(+)} \geq +1.0 V_{DC}$, $V_{IN(-)} = 0$ and $V_{OUT} = 30 V_{DC}$			1.0			1.0	μA_{DC}
Differential Input Voltage (Note 8)	Keep All $V_{IN}'s \geq 0 V_{DC}$ (or V^- , if used)			36			36	V_{DC}

Note 1: For operating at high temperatures, the LM339 must be derated based on a $+125^\circ\text{C}$ maximum junction temperature and a thermal resistance of 175°C/W which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM239 and LM139 must be derated based on a $+150^\circ\text{C}$ maximum junction temperature. The low bias dissipation and the ON-OFF characteristic of the outputs keeps the chip dissipation very small ($P_d \leq 100 \text{ mW}$), provided the output transistors are allowed to saturate.

Note 2: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. The maximum output current is approximately 20 mA independent of the magnitude of V^+ .

Note 3: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the comparators to go to the V^+ voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than $-0.3 V_{DC}$.

Note 4: These specifications apply for $V^+ = +5.0 V_{DC}$ and $-55^\circ\text{C} \leq T_A \leq +125^\circ\text{C}$, unless otherwise stated. With the LM239, all temperature specifications are limited to $-25^\circ\text{C} \leq T_A \leq +85^\circ\text{C}$ and the LM339 temperature specifications are limited to $0^\circ\text{C} \leq T_A \leq +70^\circ\text{C}$.

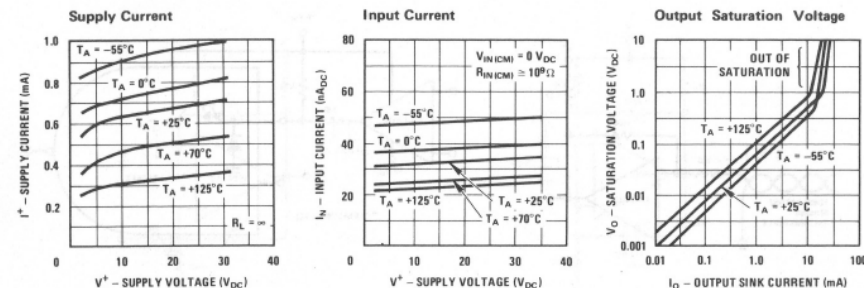
Note 5: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the reference or input lines.

Note 6: The input common-mode voltage or either input signal voltage should not be allowed to go negative by more than $0.3 V$. The upper end of the common-mode voltage range is $V^+ - 1.5 V$, but either or both inputs can go to $+30 V_{DC}$ without damage.

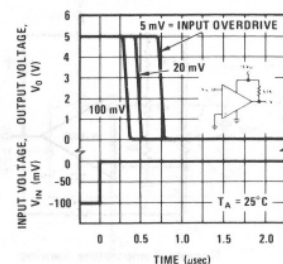
Note 7: The response time specified is for a 100 mV input step with 5.0 mV overdrive. For larger overdrive signals 300 ns can be obtained, see typical performance characteristics section.

Note 8: The positive excursions of the inputs can exceed the power supply voltage level, and if the other input voltage remains within the common-mode voltage range, the comparator will provide a proper output state. The low input voltage state must not be less than $-0.3 V_{DC}$ for $0.3 V_{DC}$ below the magnitude of the negative power supply voltage, if used.

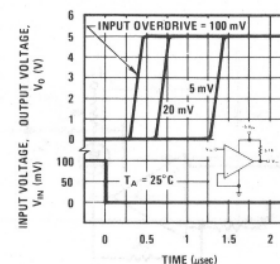
typical performance characteristics



Response Time for Various Input Overdrives — Negative Transition



Response Time for Various Input Overdrives — Positive Transition



application hints

The LM139 is a high gain, wide bandwidth device; which, like most comparators, can easily oscillate if the output lead is inadvertently allowed to capacitively couple to the inputs via stray capacitance. This shows up only during the output voltage transition intervals as the comparator changes states. Power supply bypassing is not required to solve this problem. Standard PC board layout is helpful as it reduces stray input-output coupling. Reducing the input resistors to $<10 \text{ k}\Omega$ reduces the feedback signal levels and finally, adding even a small amount (1 to 10 mV) of positive feedback (hysteresis) causes such a rapid transition that oscillations due to stray feedback are not possible. Simply socketing the I/C and attaching resistors to the pins will cause input-output oscillations during the small transition intervals unless hysteresis is used. If the input signal is a pulse waveform, with relatively fast rise and fall times, hysteresis is not required.

All pins of any unused comparators should be grounded.

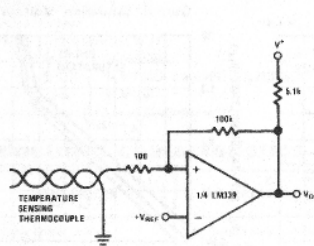
The bias network of the LM139 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of from $2V_{DC}$ to $30 V_{DC}$.

It is usually unnecessary to use a bypass capacitor across the power supply line.

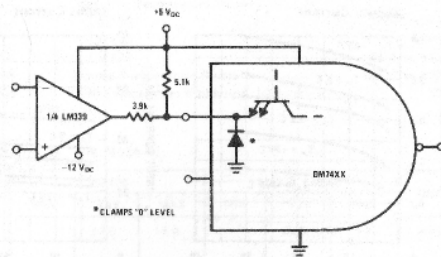
The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than $-0.3 V_{DC}$ (at 25°C). An input clamp diode and input resistor can be used as shown in the applications section.

The output of the LM139 is the uncommitted collector of a grounded-emitter NPN output transistor. Many collectors can be tied together to provide an output OR'ing function. An output "pull-up" resistor can be connected to any available power supply voltage within the permitted supply voltage range and there is no restriction on this voltage due to the magnitude of the voltage which is applied to the V^+ terminal of the LM139 package. The output can also be used as a simple SPST switch to ground (when a "pull-up" resistor is not used). The amount of current which the output device can sink is limited by the drive available (which is independent of V^+) and the β of this device. When the maximum current limit is reached (approximately 16 mA), the output transistor will come out of saturation and the output voltage will rise very rapidly. The output saturation voltage is limited by the approximately 60Ω r_{sat} of the output transistor. The low offset voltage of the output transistor (1 mV) allows the output to clamp essentially to ground level for small load currents.

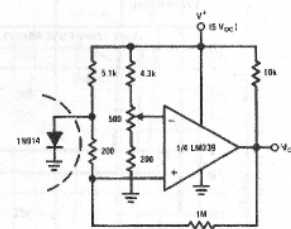
typical applications (con't)



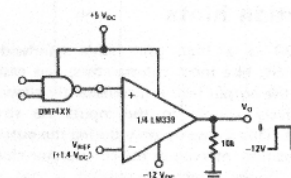
Ground Referenced Thermocouple in Single Supply System



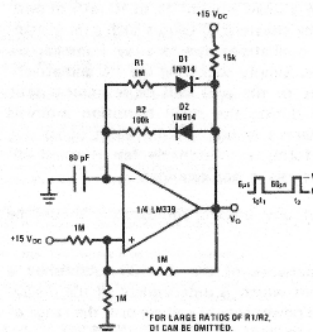
MOS to TTL Logic Translator



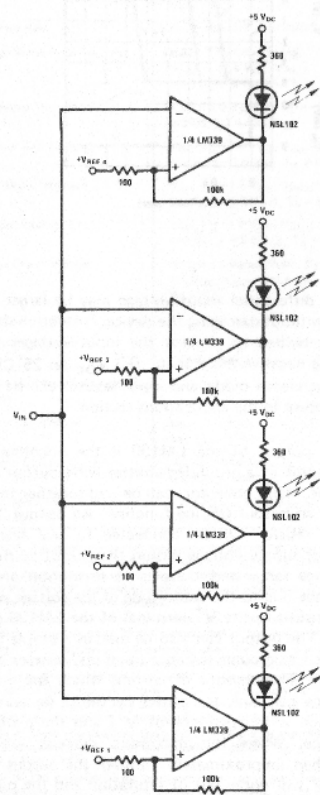
Remote Temperature Sensing



TTL to MOS Logic Converter

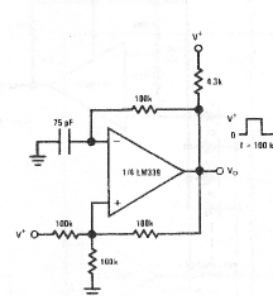


Pulse Generator

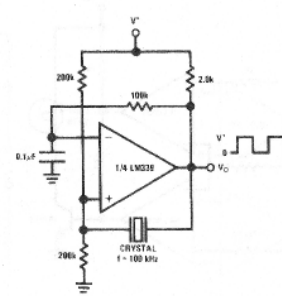


Visible Voltage Indicator

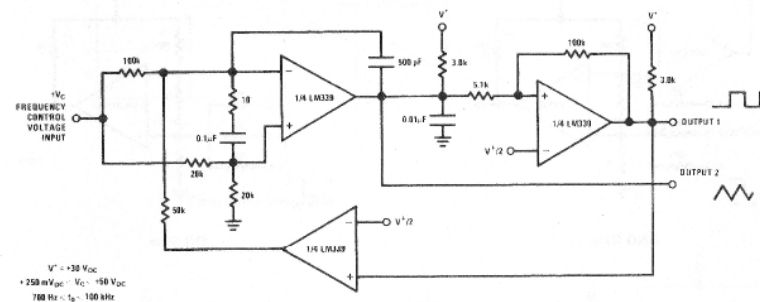
typical applications (con't) ($V^+ = 15V_{DC}$)



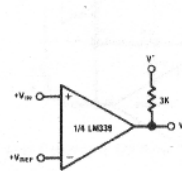
Squarewave Oscillator



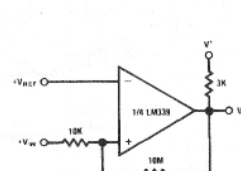
Crystal Controlled Oscillator



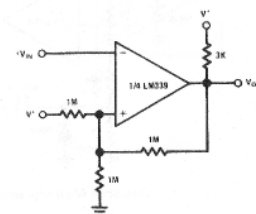
Two-Decade High-Frequency VCO



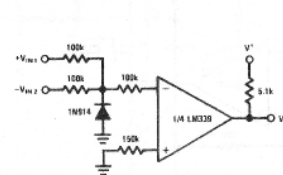
Basic Comparator



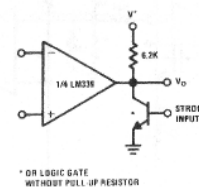
Non-Inverting Comparator with Hysteresis



Inverting Comparator with Hysteresis

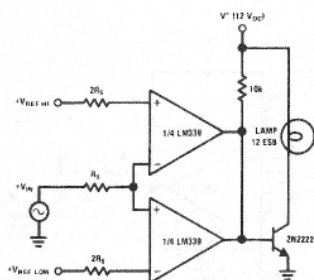


Comparing Input Voltages of Opposite Polarity

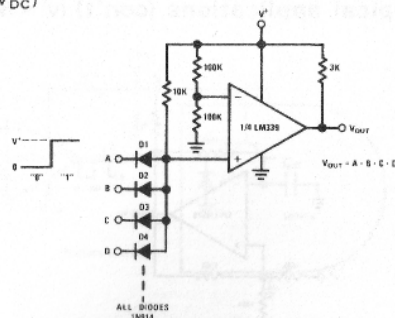


Output Strobing

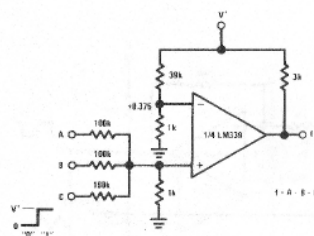
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



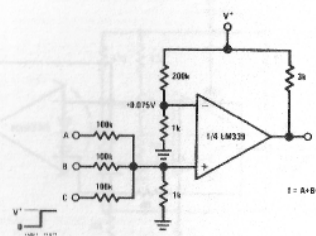
Limit Comparator



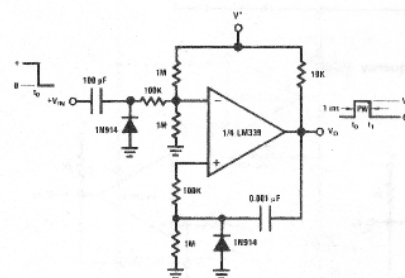
Large Fan-in AND Gate



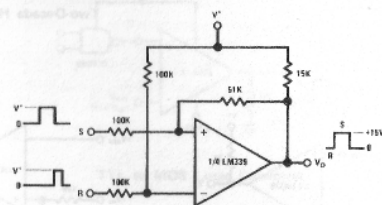
AND Gate



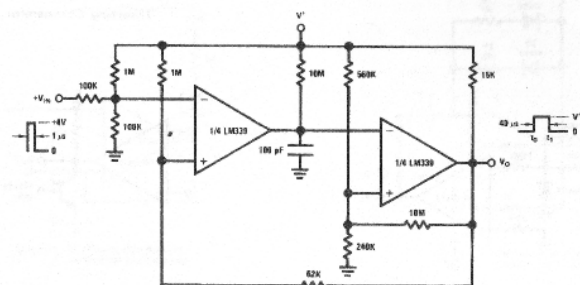
OR Gate



One-Shot Multivibrator

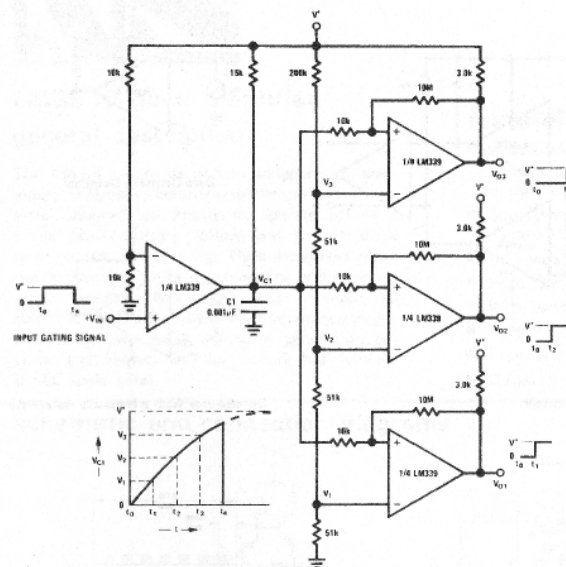


Bi-Stable Multivibrator

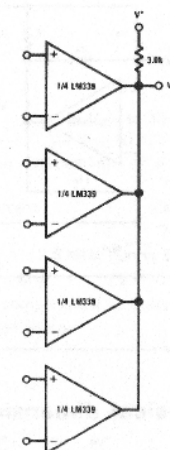


One-Shot Multivibrator with Input Lock Out

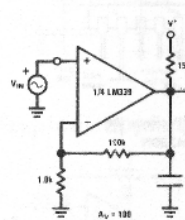
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



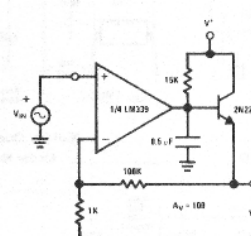
Time Delay Generator



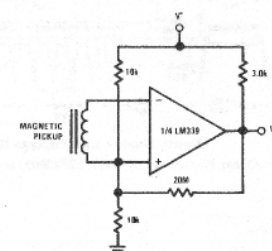
ORing the Outputs



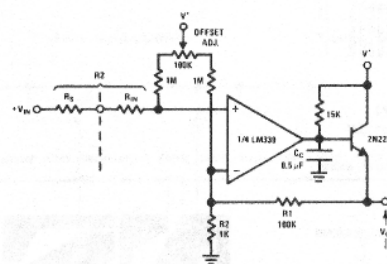
Low Frequency Op Amp



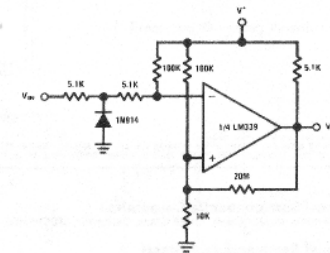
Low Frequency Op Amp
($V_0 = 0\text{ V}$ for $V_{\text{IN}} = 0\text{ V}$)



Transducer Amplifier

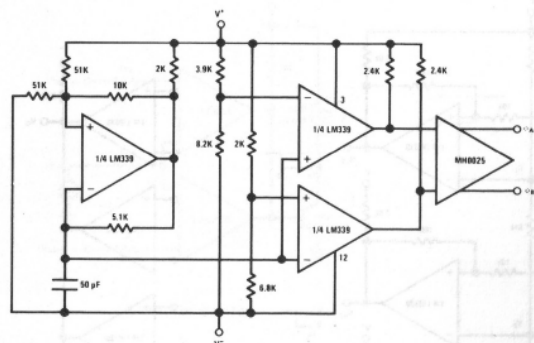


Low Frequency Op Amp with Offset Adjust

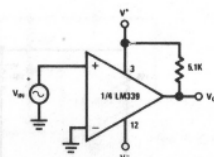


Zero Crossing Detector (Single Power Supply)

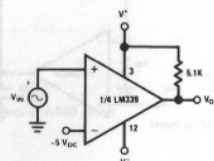
split-supply applications ($V^+ = +15 V_{DC}$ and $V^- = -15 V_{DC}$)



MOS Clock Driver

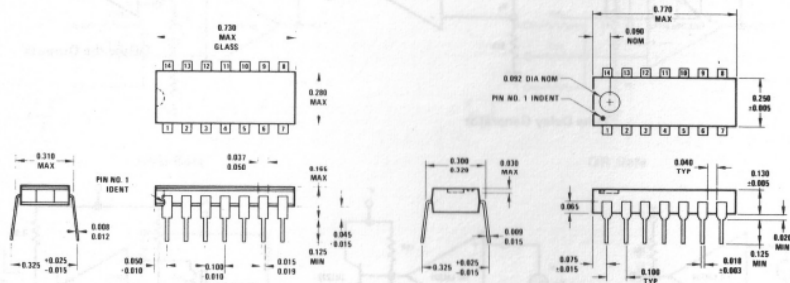


Zero Crossing Detector



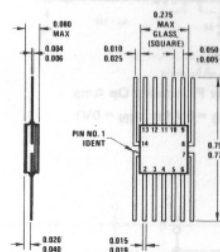
Comparator With a Negative Reference

physical dimensions



Cavity Dual-In-Line Package (D)
Order Numbers LM139D, LM239D, or LM339D

Molded Dual-In-Line Package (N)
Order Number LM339N



Flat Package (F)
Order Number LM139F

Manufactured under one or more of the following U.S. patents: 3083262, 3189754, 3231767, 3303356, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440490, 3518750, 3519897, 3557431, 3560765, 3566718, 3571630, 3575609, 3576559, 3593069, 3597640, 3607469, 3617859, 3631312, 3633052, 3638131, 3648071, 3651565, 3693248.

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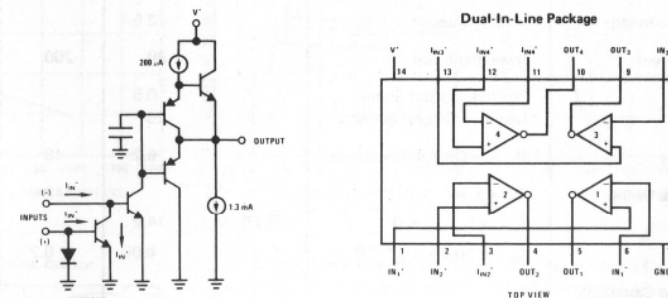
LM3900 quad amplifier general description

The LM3900 consists of four independent, dual input, internally compensated amplifiers which were designed specifically to operate off of a single power supply voltage and to provide a large output voltage swing. These amplifiers make use of a current mirror to achieve the non-inverting input function. Application areas include: AC amplifiers, RC active filters; low frequency triangle, squarewave and pulse waveform generation circuits, tachometers and low speed, high voltage digital logic gates.

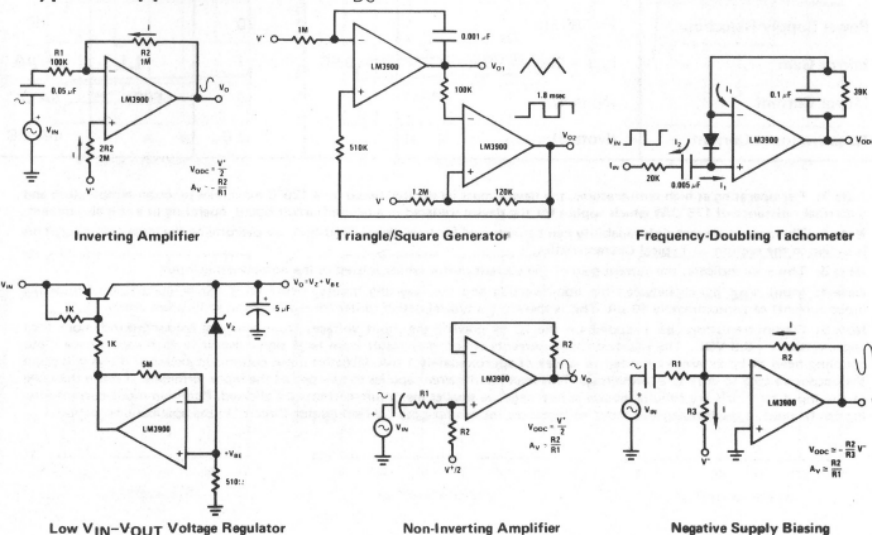
features

- Wide single supply voltage range $4 V_{DC}$ to $36 V_{DC}$ or dual supplies $\pm 2 V_{DC}$ to $\pm 18 V_{DC}$
- Supply current drain independent of supply voltage
- Low input biasing current 30 nA
- High open-loop gain 70 dB
- Wide bandwidth 2.5 MHz (Unity Gain)
- Large output voltage swing $(V^+ - 1) V_{p-p}$
- Internally frequency compensated for unity gain
- Output short-circuit protection

schematic and connection diagrams



typical applications ($V^+ = 15 V_{DC}$)



absolute maximum ratings

Supply Voltage	+36 VDC
Power Dissipation ($T_A = 25^\circ\text{C}$) (Note 1)	570 mW
Input Currents, I_{IN}^+ or I_{IN}^-	20 mA DC
Output Short Circuit Duration — One Amplifier $T_A = 25^\circ\text{C}$ (See Application Hints)	Continuous
Operating Temperature Range	0°C to $+70^\circ\text{C}$
Storage Temperature Range	-65°C to $+150^\circ\text{C}$
Lead Temperature (Soldering, 60 sec)	300°C

electrical characteristics ($V^+ = +15$ VDC and $T_A = 25^\circ\text{C}$ unless otherwise noted)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Open Loop					
Voltage Gain	$f = 100$ Hz	1200	2800		V/V
Input Resistance	Inverting Input		1		M Ω
Output Resistance			8		k Ω
Unity Gain Bandwidth	Inverting Input		2.5		MHz
Input Bias Current	Inverting Input		30	200	nA
Slew Rate	Positive Output Swing		0.5		V/ μs
	Negative Output Swing		20		V/ μs
Supply Current	$R_L = \infty$ On All Amplifiers		6.2	10	mA DC
Output Voltage Swing	$R_L = 5.1$ k				
V_{OUT} High	$I_{IN}^- = 0$, $I_{IN}^+ = 0$	13.5	14.2		VDC
V_{OUT} Low	$I_{IN}^- = 10$ μA , $I_{IN}^+ = 0$		0.09	0.2	VDC
Output Current Capability					
Source		3	10		mA DC
Sink	(Note 2)	0.5	1.3		mA DC
Power Supply Rejection	$f = 100$ Hz		70		dB
Mirror Gain	$I_{IN}^+ = 200$ μA (Note 3)	0.90	1	1.1	$\mu\text{A}/\mu\text{A}$
Mirror Current	(Note 4)		10	500	μA DC
Negative Input Current	(Note 5)		1.0		mA DC

Note 1: For operating at high temperatures, the device must be derated based on a 125°C maximum junction temperature and a thermal resistance of $175^\circ\text{C}/\text{W}$ which applies for the device soldered in a printed circuit board, operating in a still air ambient.

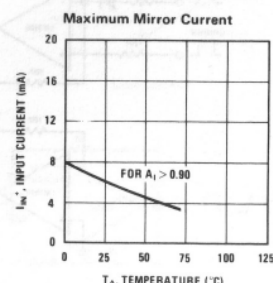
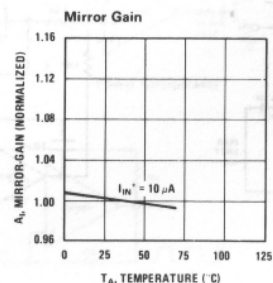
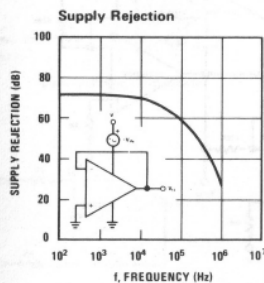
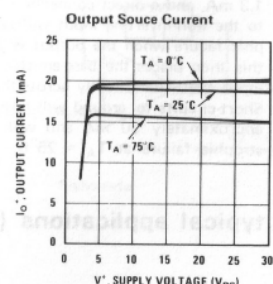
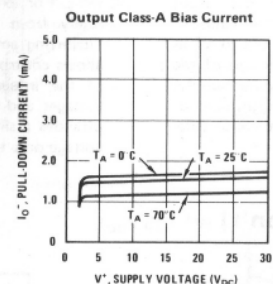
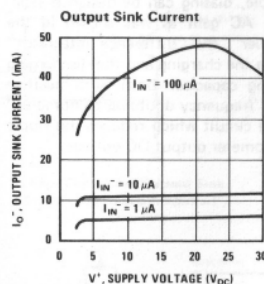
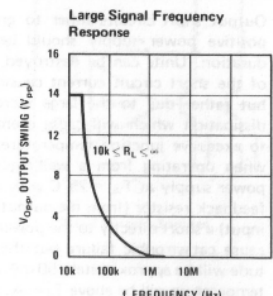
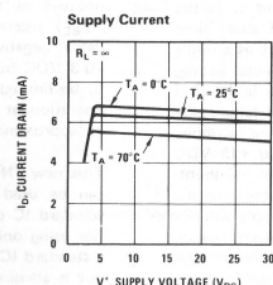
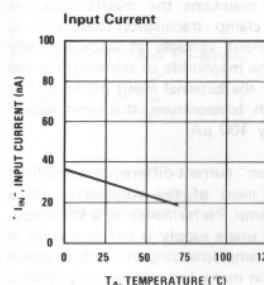
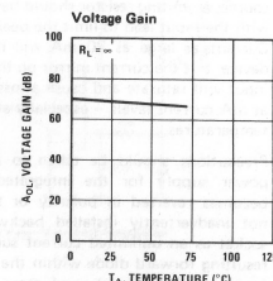
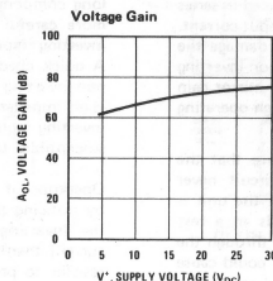
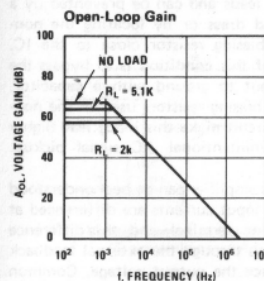
Note 2: The output current sink capability can be increased for large signal conditions by overdriving the inverting input. This is shown in the section on Typical Characteristics.

Note 3: This spec indicates the current gain of the current mirror which is used as the non-inverting input.

Note 4: Input V_{BE} match between the non-inverting and the inverting inputs occurs for a mirror current (non-inverting input current) of approximately 10 μA . This is therefore a typical design center for many of the application circuits.

Note 5: Clamp transistors are included on the IC to prevent the input voltages from swinging below ground more than approximately -0.3 VDC. The negative input currents which may result from large signal overdrive with capacitance input coupling need to be externally limited to values of approximately 1 mA. Negative input currents in excess of 4 mA will cause the output voltage to drop to a low voltage. This maximum current applies to any one of the input terminals. If more than one of the input terminals are simultaneously driven negative smaller maximum currents are allowed. Common-mode current biasing can be used to prevent negative input voltages; see for example the "Differentiator Circuit" in the applications section.

typical performance characteristics



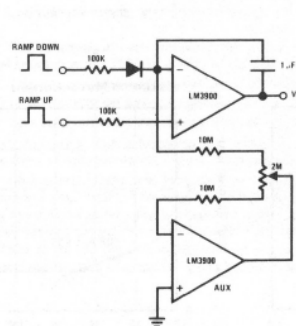
application hints

When driving either input from a low-impedance source, a limiting resistor should be placed in series with the input lead to limit the peak input current. Currents as large as 20 mA will not damage the device, but the current mirror on the non-inverting input will saturate and cause a loss of mirror gain at mA current levels — especially at high operating temperatures.

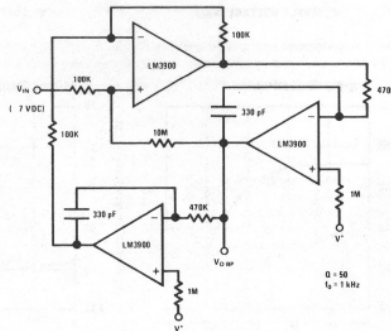
Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive junction temperatures. For example, when operating from a well-regulated +15 VDC power supply at $T_A = 25^\circ\text{C}$ with a 100 k Ω shunt-feedback resistor (from the output to the inverting input) a short directly to the power supply will not cause catastrophic failure but the current magnitude will be approximately 50 mA and the junction temperature will be above T_J max. Larger feedback resistors will reduce the current, 11 M Ω provides approximately 30 mA, an open circuit provides 1.3 mA, and a direct connection from the output to the non-inverting input will result in catastrophic failure when the output is shorted to V^+ as this then places the base-emitter junction of the input transistor directly across the power supply. Short-circuits to ground will have magnitudes of approximately 30 mA and will not cause catastrophic failure at $T_A = 25^\circ\text{C}$.

typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



Low-Drift Ramp & Hold Circuit



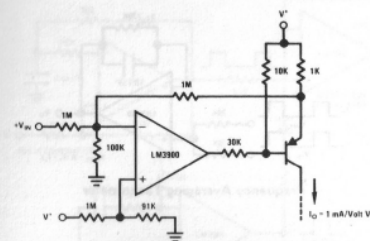
Bi-Quad Active Filter
(2nd Degree State-Variable Network)

Unintentional signal coupling from the output to the non-inverting input can cause oscillations. This is likely only in breadboard hook-ups with long component leads and can be prevented by a more careful lead dress or by locating the non-inverting input biasing resistor close to the IC. A quick check of this condition is to bypass the non-inverting input to ground with a capacitor. High impedance biasing resistors used in the non-inverting input circuit make this input lead highly susceptible to unintentional AC signal pickup.

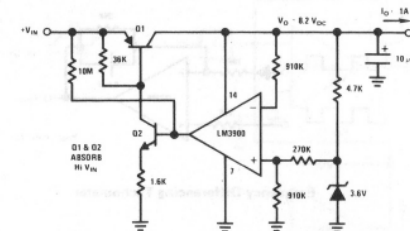
Operation of this amplifier can be best understood by noticing that input currents are differenced at the inverting-input terminal and this difference current then flows through the external feedback resistor to produce the output voltage. Common mode current biasing is generally useful to allow operating with signal levels near ground or even negative as this maintains the inputs biased at $+V_{BE}$. Internal clamp transistors (see note 5) catch negative input voltages at approximately -0.3 VDC but the magnitude of current flow has to be limited by the external input network. For operation at high temperature, this limit should be approximately 100 μA .

This new "Norton" current-differencing amplifier can be used in most of the applications of a standard IC op amp. Performance as a DC amplifier using only a single supply is not as precise as a standard IC op amp operating with split supplies but is adequate in many less critical applications. New functions are made possible with this amplifier which are useful in single power supply systems. For example, biasing can be designed separately from the AC gain as was shown in the "inverting amplifier", the "difference integrator" allows controlling the charging and the discharging of the integrating capacitor both with positive voltages, and the "frequency doubling tachometer" provides a simple circuit which reduces the ripple voltage on a tachometer output DC voltage.

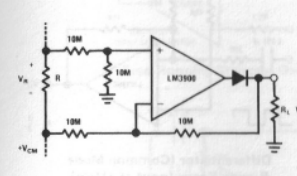
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



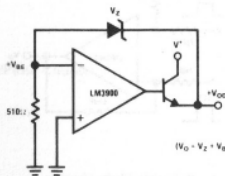
Voltage-Controlled Current Source
(Transconductance Amplifier)



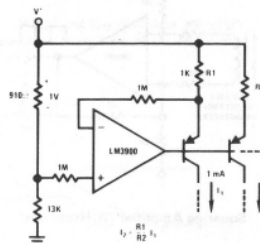
Hi V_{IN} , Lo $(V_{IN} - V_O)$ Self-Regulator



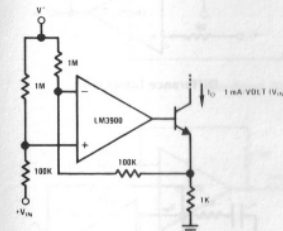
Ground-Referencing a
Differential Input Signal



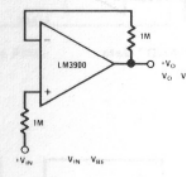
Voltage Regulator



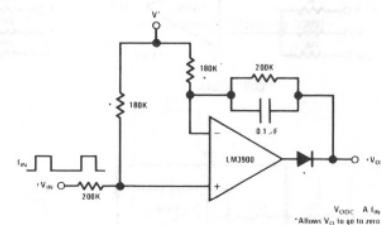
Fixed Current Sources



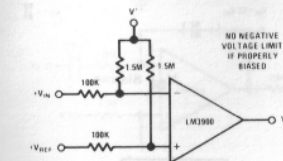
Voltage-Controlled Current Sink
(Transconductance Amplifier)



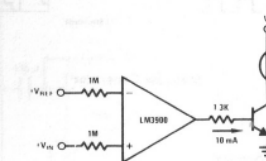
Buffer Amplifier



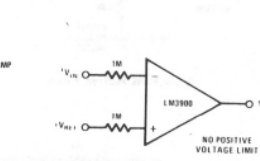
Tachometer



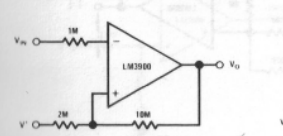
Low-Voltage Comparator



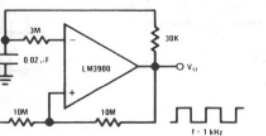
Power Comparator



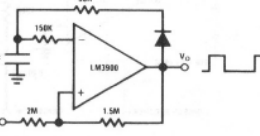
Comparator



Schmitt-Trigger

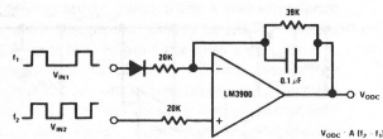


Square-Wave Oscillator

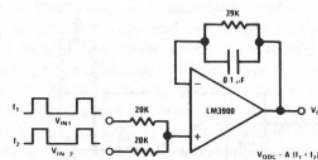


Pulse Generator

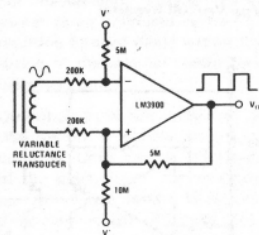
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



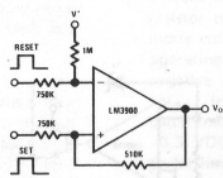
Frequency Differencing Tachometer



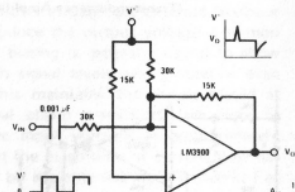
Frequency Averaging Tachometer



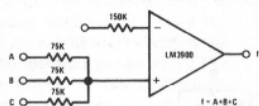
Squaring Amplifier (W/Hysteresis)



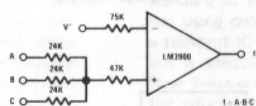
Bi-Stable Multivibrator



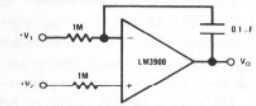
Differentiator (Common-Mode Biasing Keeps Input at $+V_{\text{BE}}$)



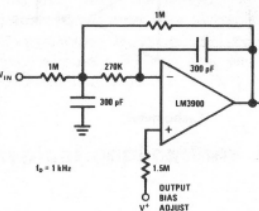
"OR" Gate



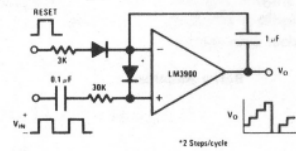
"AND" Gate



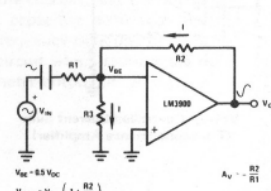
Difference Integrator



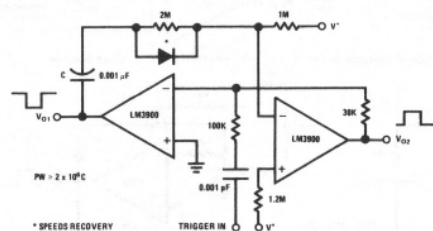
Low Pass Active Filter



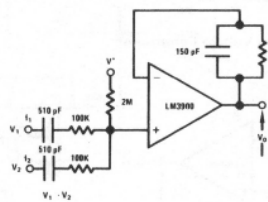
Staircase Generator



V_{BE} Biasing

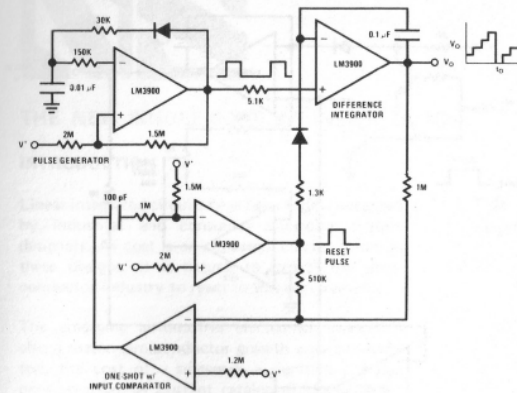


One-Shot Multivibrator

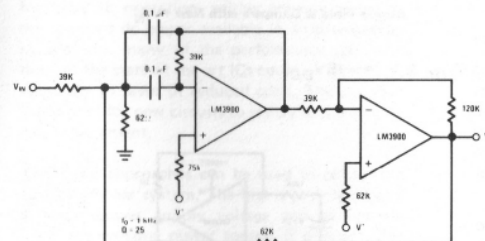


Low-Frequency Mixer

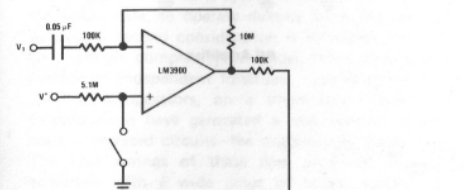
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



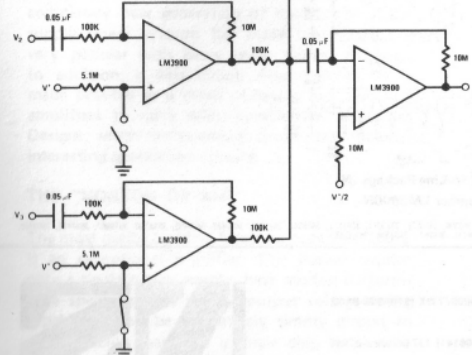
Free-Running Staircase Generator/Pulse Counter



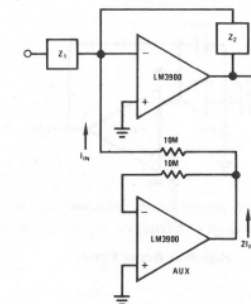
Bandpass Active Filter



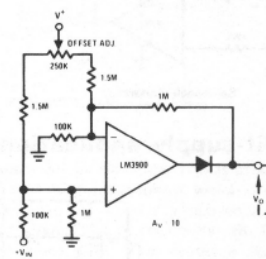
Power Amplifier



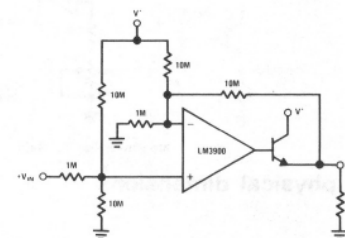
Channel Selection by DC Control (or Audio Mixer)



Supplying I_{IN} with Aux. Amp (to Allow High Z Feedback Networks)

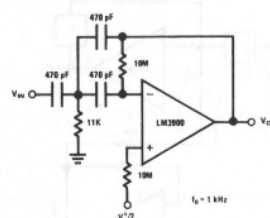


Non-Inverting DC Gain to (0,0)

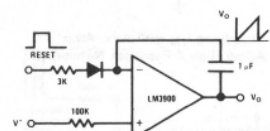


One-Shot w/ DC Input Comparator

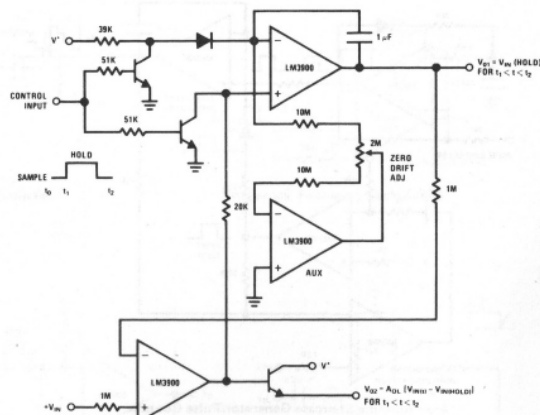
typical applications (con't) ($V^+ = 15\text{ V}_{\text{DC}}$)



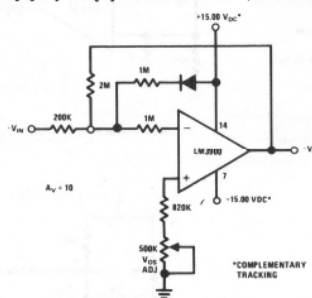
High Pass Active Filter



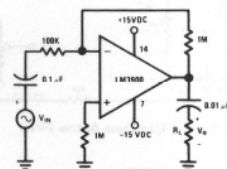
Sawtooth Generator

Sample-Hold & Compare with New $+V_{IN}$

split-supply applications ($V^+ = +15V_{DC}$ & $V^- = -15V_{DC}$)

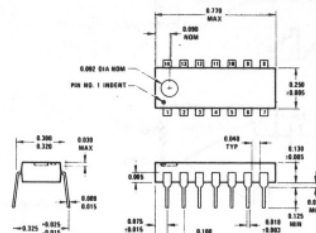


Non-Inverting DC Gain



AC Amplifier

physical dimensions



Molded Dual-In-Line Package (N)
Order Number LM3900N

Manufactured under one or more of the following U.S. patents: 3083262, 3189758, 3231797, 3303356, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440498, 3518750, 3519897, 3557431, 3560765, 3566218, 3571630, 3575608, 3579050, 3593069, 3597540, 3607469, 3617859, 3631312, 3633052, 3638121, 3648021, 3651585, 3692248

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Thomas M. Frederiksen
National Semiconductor

THE NEW SINGLE-SUPPLY LINEAR QUADS

INTRODUCTION

Linear integrated circuits have been widely accepted by industrial and consumer electronic system designers. As cost is an important consideration in these designs, it is natural to expect the semiconductor industry to react to this requirement.

The emerging automotive electronics market is also a major semiconductor growth area and here, too, the cost of a system is a significant design consideration. A current catalog of available ICs lists digital circuits which were designed for +5.0V dc operation and linear circuits which were designed for $\pm 15V$ dc operation—neither are well suited to the standard dc power available in an automobile. In addition, many of the performance specifications of the state-of-the-art ICs could be sacrificed, especially in favor of reduced costs. Thus, a need has existed for new circuits to satisfy this emerging new requirement.

Two basic approaches can be used to reduce the cost of a linear system. The first is to only require a single power supply voltage and to operate from any existing power source, if possible. For example, this may be the +5.0V_{DC} supply which is already required by digital circuits which may also be used in the same system or; in the case of the automobile, to operate directly from the car battery. A second consideration is to reduce the basic circuit complexity to allow fabricating a number of independent functions, such as amplifiers or comparators, on a single chip. These considerations have generated a new concept in linear integrated circuits—the single-supply quads. The cost savings of these new products, the operation with a wide range of power supply voltage (3.0 to 30 V_{DC}) and the possibilities of a completely new generation of lower cost single-supply linear systems has made these products very popular with every linear system designer. In addition, a new circuit design technique is made possible as a result of having four matched amplifiers to work with—Symmetrical Amplifier Designs; which can be used to provide a number of interesting application circuits.

THE "NORTON OP AMP"

The most useful building block for control systems is an operational amplifier. This should require only a single power supply, have modest performance specifications, a large output voltage swing capability, and be a relatively simply circuit to allow placing many on a single chip to provide multiple circuits in a single package.

One of the simplest basic gain stages is the common-emitter amplifier shown in Figure 1. If

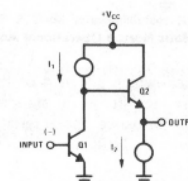


FIGURE 1. Simple Gain Stage

this is modified as shown in Figure 2, a non-inverting input can be obtained. This is provided by the standard IC current mirror which is composed of CR1 and Q3. Current which enters the non-inverting input, I_{IN2} , essentially all flows through the diode CR1. This causes a voltage

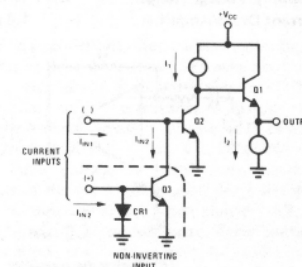


FIGURE 2. Obtaining a Non-Inverting Input

drop across CR1 which corresponds to this input current magnitude and, as this same voltage is applied to a matched device, Q3, this transistor is biased to also conduct I_{IN2} . This mirroring or reflecting of I_{IN2} about ground gives a desired current differencing at the inverting input node. In operation, this difference or error current flows through the external shunt feedback resistor which generates the output voltage signal. Notice that input currents are compared, not input voltages—as with the conventional operational amplifiers. To reduce the dc input bias current, the circuit is modified as shown in Figure 3 and incorporates an emitter-follower transistor, Q1. Closed-loop stability is guaranteed by the on-chip frequency compensating capacitor, $C = 3.0$ pF. This small value of capacitance can be economically provided

on the IC chip. As a result of the internal frequency compensation, only 3 pins are needed

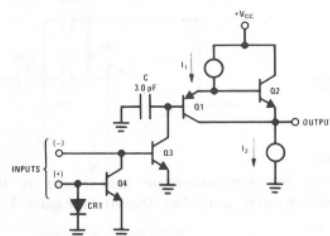
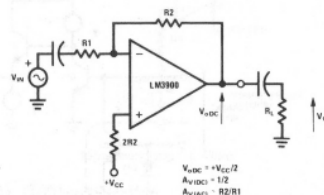


FIGURE 3. Basic Norton Operational Amplifier

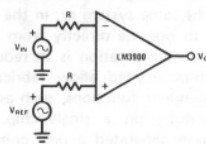
for each amplifier—which allows 4 of these operational amplifiers to fit in a standard 14-pin package. The performance characteristics of this amplifier are given in Table I.

TABLE I. Typical Characteristics of the Norton Operational Amplifier (LM3900)

Open Loop Voltage Gain	70 dB
Unity Gain Frequency	2.5 MHz
Dc Input Current (Inverting Input)	35 nA
Output Voltage Swing ($V_{CC} = 15V$)	14 V_{P-P}
Output Current Capability	
Source	5.0 mA
Sink	1.0 mA
Power Supply Voltage Range	3.0V to 30V
Bias Current Drain/Amplifier	1.4 mA

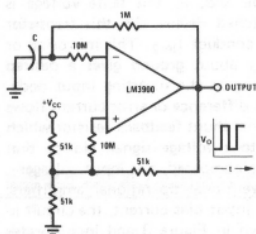


(A) Biasing the Amplifier

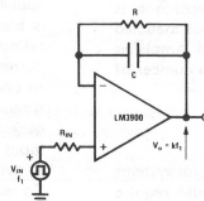


(B) Comparator

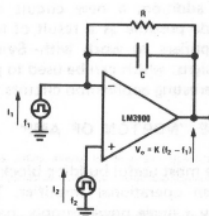
FIGURE 5. Basic Applications of Norton Operational Amplifier



(A) Squarewave Oscillator



(1) VOLTAGE PULSES



(2) DIFFERENCING CURRENT PULSES

(B) Tachometer Averaging Circuits

FIGURE 6. System Applications of Norton Operational Amplifier

A new symbol, Figure 4, has been adopted for this "Norton Amplifier." This is recommended to avoid using the standard op amp symbol as the basic operation is different. The current source symbol between the inputs implies this new current-mode of operation. In addition, it signifies that current is removed from the (-) input terminal.

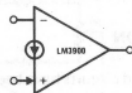


FIGURE 4. New Norton Amplifier Symbol

Also, the current arrow on the (+) input lead is used to indicate that this functions as a current input. The use of this symbol is helpful in understanding the operation of the application circuits and also in doing additional design work with the Norton Amplifier.

A few basic application circuits using this new input current-differencing amplifier are shown in Figure 5. Figure 5a indicates how the two inputs can be separately used to provide both a prescribed ac gain and a desired dc output operating point. A simple comparator is shown in Figure 5b where input resistors are used to convert from input voltages to input currents—the resulting currents are then compared. The single-capacitor square wave oscillator circuit of Figure 6a is a useful ac source or clock circuit for a digital system and can be easily modified to be unsymmetrical or to

be voltage variable. Some interesting tachometer applications are shown in Figure 6b where either voltage or current input pulses are converted to a dc output voltage which can be made a function of a single input frequency, the sum of two input frequencies, or the difference between two input frequencies where the operational amplifier is accomplishing both the averaging and the summing or differencing functions.

A useful application of the input mirror circuit is shown in Figure 7. This is a photovoltaic photocell amplifier which biases the cell with essentially zero volts across it. When illuminated, photocurrent is extracted from the shunt feedback resistor, R_2 , and is entered into the (+) input terminal. The mirror circuit then causes this same current to enter the (-) input terminal. The total current flowing through the shunt feedback resistor is therefore doubled so the gain is doubled.

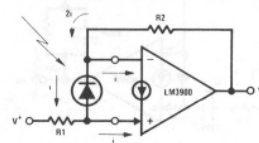


FIGURE 7. A Current-Doubling Photocell Amplifier

Another application of the input "current mirror" is shown in Figure 8. If a "current mirror," CR1 and Q1, is added to the input of a typical IC op amp (741), the gain-bandwidth product can be extended. The isolation provided by the "current mirror" allows a constant unity voltage gain feedback for the main inverting amplifier. This

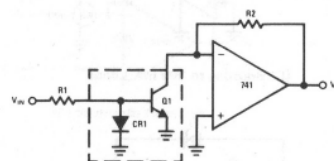


FIGURE 8. Extending the Gain-Bandwidth Product

means that large values of gain can be achieved at high frequencies and the dominate limit is due to the slow rate of the amplifier. This operational mode is useful for signal frequencies in the 50 kHz to 1 MHz range as would be encountered in IF or carrier frequency applications. The "Norton Amplifier" allows this increased gain-bandwidth product in the non-inverting gain stage of Figure 9.

A one-shot multivibrator can be realized with a small number of external components as shown in Figure 10. The input trigger is differentiated by the RC network R1 C1. The bias resistor, R2, keeps the output voltage low during the quiescent

state. A negative input trigger causes the output to go positive and the charging current of the pulse forming capacitor, C2, (as limited by R3) enters

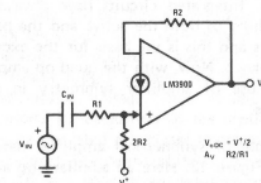


FIGURE 9. A Wide Bandwidth Non-Inverting Amplifier

the (+) input and reinforces the positive output voltage state. The pulse width is terminated when C2 becomes charged as the bias current from R2 again causes the output voltage to switch low.

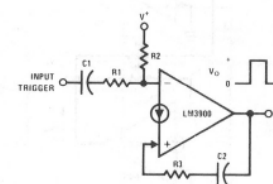


FIGURE 10. One-Shot Multivibrator

For dc applications, the base-emitter voltage which exists at the (-) input can be tracked out using the basic idea which is shown in Figure 11. The first amplifier, amp 1, establishes an output reference voltage which consists of the zero temperature coefficient (OTC) Zener, V_Z , in addition to the (-) input voltage, V^- . This same input voltage exists at the (-) input of amplifier 2 and therefore the voltage across the input resistor, R2, is only the temperature compensated Zener voltage, V_Z . This allows the input current, I_{IN} , to be independent of temperature even though the (-) input voltages, V^- , are changing with temperature.

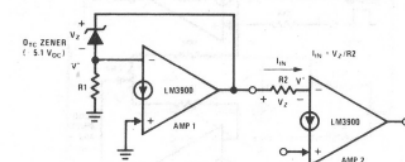


FIGURE 11. Obtaining a 0TC Input Current

An interesting application of a quad amplifier is to make use of the natural symmetry which exists between the amplifiers. This is a new design concept and is the next logical step in symmetrical circuit design. Probably the first use of symmetrical

circuit design was to place two NPN transistors on the same heat sink and to use these for the input stage of a discrete op amp. Next came two NPN transistors in the same package for this application. Integrated circuits have always had good matching of both the active and the passive components and this is the basis for the excellent dc performance. Now, with the quad op amps, we can make use of amplifier symmetry in many applications.

One example of symmetrical amplifier design is shown in Figure 12. Here an auxiliary op amp is used to supply the input current to a second op amp. This technique reduces the "effective" input current of this second op amp and therefore we have a low input current amplifier available. There

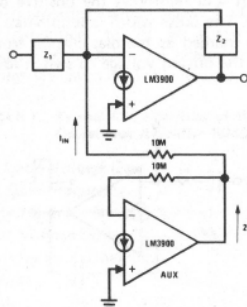


FIGURE 12. Supplying I_{IN} With Aux Amp (To Allow High Z Feedback Networks)

are many applications where this offers advantages. For example, a low drift ramp and hold circuit is shown in Figure 13 where an adjustment can be made to exactly cancel the input current. This can be used to zero the output voltage drift of the integrating op amp. The two control inputs will cause the output voltage to ramp up or to ramp down and if both inputs are at ground level, the output voltage will be in a hold state.

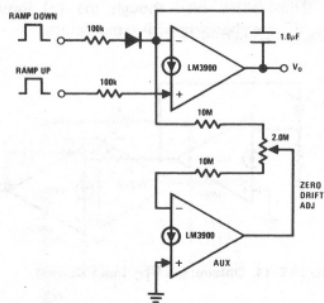
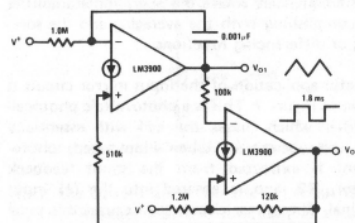


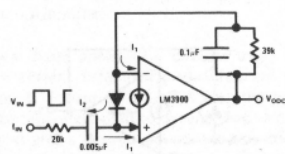
FIGURE 13. Low-Drift Ramp and Hold Circuit

A collection of some interesting application circuits which make use of the unique features of the

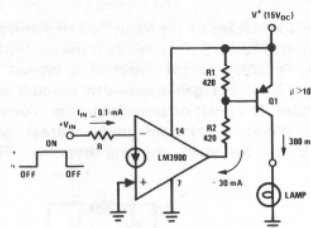
Norton quad are shown in Figure 14. An interconnection of a dual slope integrator and a Schmitt trigger make-up the triangle/square generator of Figure 14a. The tachometer of Figure 14b provides a positive output voltage for positive input voltage pulses and the addition of the diode



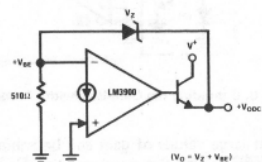
(A) Triangle/Square Generator



(B) Frequency-Doubling Tachometer



(C) Boosting to 300 mA Loads



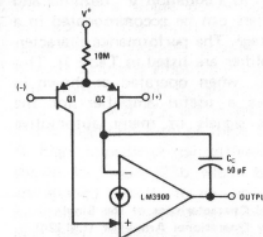
(D) Voltage Regulator

FIGURE 14. Applications of the Norton

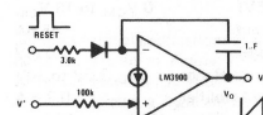
across the inputs gives an effective doubling of the input frequency to reduce ripple on the output voltage. The Norton amplifier can sink large currents and as shown in Figure 14c can drive a single external transistor to provide a relatively simple power amplifier. Simply adding a Zener diode from output to inverting input is the basis of a series voltage regulator. If a Zener biasing

resistor and an output emitter follower are added, the voltage regulator of Figure 14d results.

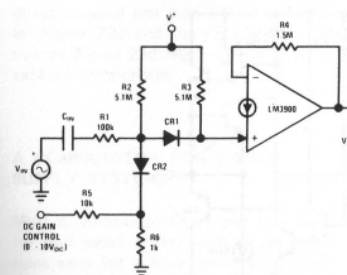
Some unusual application circuits are possible with this Norton amplifier. Figure 15a shows how a differential input stage can be added. A free running staircase generator, complete with the pulse generator, integrator, output voltage comparator and reset pulse generator is shown in Figure 15b. The faster negative slew rate of the Norton amplifier allows the generation of better sawtooth waveforms than is possible with a standard op amp. The relatively simple circuit of Figure 15c provides an excellent sawtooth waveform and the reset can occur at any time to initiate a new sweep. A dc gain controlled amplifier is shown in Figure 15d where the diodes CR1 and CR2 are used to divert the input signal for a wide gain control range. A phase-locked loop is shown in Figure 15e which uses three amplifiers and is useful in low frequency control applications.



(A) Adding a Differential Input Stage



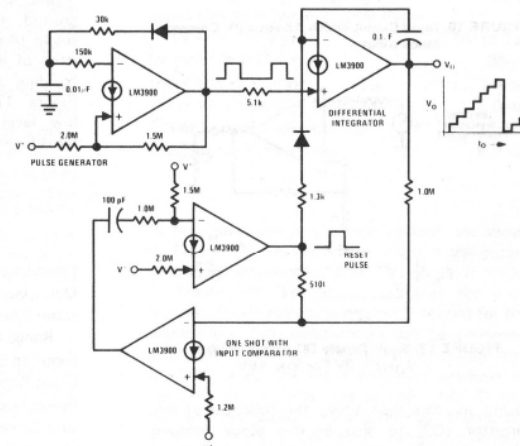
(C) Sawtooth Generator



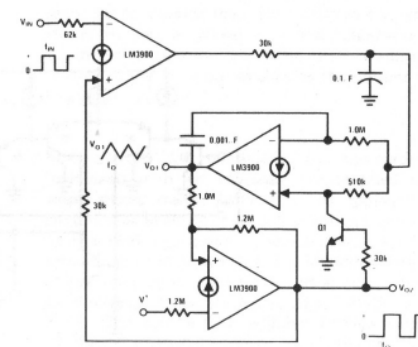
(D) A DC Gain Controlled Amplifier

THE TRUE DIFFERENTIAL INPUT QUAD

For improved dc performance, a "true differential input" single-supply quad is now available. The new op amp circuit has many advantages for a single power supply linear system. When a standard IC operational amplifier is operated from only a single power supply voltage, the minimum input common mode voltage range of approximately 2.0V limits its usefulness as the input terminals cannot be operated any closer to ground than this 2.0V_{OC} limit. The modified input circuit shown in Figure 16 will provide an input common mode voltage range of 0V (it actually extends slightly below ground)—even though only a single power supply is used. This input stage allows all of the input biasing conveniences of ground, such as providing dc gain for low level transducer signals which are ground referenced (Figure 17). Therefore, it would be useful to make an amplifier for low output voltage transducers, such as thermocouples.



(B) Free Running Staircase Generator/Pulse Counter



(E) Phase-Locked Loop

FIGURE 15. Some Unusual Applications of the Norton Quad

The circuit operation of Figure 16 can be determined by considering, for example, that the non-inverting (+) input is at ground potential. The V_{BE} rise due to the input transistor, Q4, places this emitter above ground by one diode drop (V_{BE}). The second transistor, Q3, can operate in the linear region with 0V collector-base voltage

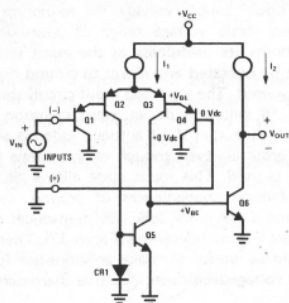


FIGURE 16. Input Circuit Which Allows a 0V Common Mode Input

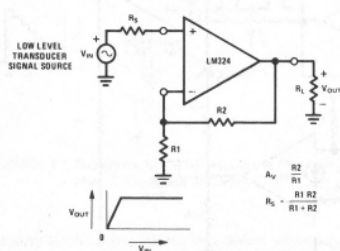


FIGURE 17. Single Supply DC Amplifier With $V_{OUT} \cong 0V$ For $V_{IN} = 0V$

biasing and this then allows the collector of this transistor (Q3) to also be one diode forward voltage drop above ground. Notice that to bring the output transistor, Q6, into conduction only

requires that the base of this transistor (Q6) be at V_{BE} , which means that a linear output can be obtained even though the input leads are at ground potential. This has proven to be a very useful differential input stage for single power supply applications.

Starting with the input circuit of Figure 16 and adding frequency compensation and an output stage, the single-supply operational amplifier of Figure 18 can be obtained. To reduce input offset voltage due to loading of the second stage the Darlington pair Q10 and Q11 has been added. A PNP transistor, Q9, has also been added to reduce the $2V_{BE}$ of the Darlington pair to maintain the 0V input common mode voltage operation. Frequency compensation is provided by the on-chip capacitor, C_C (5.0 pF), and the output load is driven by the Darlington emitter-follower transistors, Q5 and Q6. As each amplifier requires 3 pins, in addition to a common V^+ terminal and ground, 4 amplifiers can be accommodated in a single 14-pin package. The performance characteristics of this amplifier are listed in Table II. This building block IC, when operated as shown in Figure 17, makes a useful amplifier for the low level output signals of many automotive transducers.

TABLE II. Typical Characteristics of the Single Supply Operational Amplifier (LM324)

Open Loop Voltage Gain	100 dB
Unity Gain Frequency	1.0 MHz
Input Common Mode Voltage Range ($V^+ = 15V$)	0 V_{CM} to 13 V_{CM}
Input dc Bias Current	45 nA
Input Offset Voltage	2.0 mV
Power Supply Voltage Range	3.0V to 30V
Bias Current Drain/Amplifier	0.2 mA
Output Voltage Swing ($V_{CC} = 15V$)	13 V_{P-P}
Output Drive Current Capability	40 mA

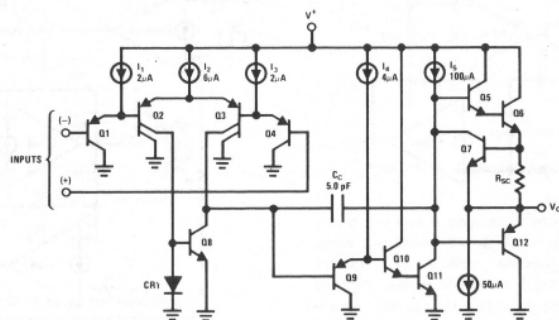


FIGURE 18. Single Supply Operational Amplifier

This amplifier has also included temperature compensation in the design of the bias circuitry which provides: an input bias current which is temperature compensated, a total power supply current drain which is temperature compensated and both the dc gain and the unity gain cross frequency (the open loop gain characteristics) are temperature compensated.

We can make use of the symmetry between the op amps to reduce the input current as shown in Figure 19. An application of this concept is the low drift peak detector which is shown in Figure 20. This circuit has high input impedance, low output impedance and compensates for the input current loading of both amplifiers.

Some applications of the true differential input Quad are shown in Figure 21. The emphasis in these application circuits is the operation from only a single power supply voltage and the use of the input common mode voltage range which includes ground. For example, a 4 input summing amplifier is shown in Figure 21a. The inputs V_1 and V_2 are non-inverting and the inputs V_3 and V_4 are inverting so the output is the algebraic sum of these four input signals. A high impedance dc differential amplifier is shown in Figure 21b where both input signals are applied directly to non-inverting inputs. This minimizes the loading on these input lines. A high input impedance adjustable-gain instrumentation amplifier is shown in Figure 21c. An interconnection of a dual slope integrator and a Schmitt trigger provides a voltage controlled oscillator, Figure 21d.

Some additional applications of the true differential quad are shown in Figure 22. The higher output current capability (compared to a standard IC op amp) allows a light emitting diode (LED) to be directly driven by the amplifier, Figure 22a. The zero volt input common mode voltage range is again made use of in the photovoltaic photocell amplifier of Figure 22b where there is essentially zero volts across the photocell and only one resistor is needed to complete the circuit. A direct coupled low pass RC active filter is shown in Figure 22c and the high compliance current sink of Figure 22d requires a minimum number of external components.

A COMPARATOR FOR SINGLE SUPPLY SYSTEMS

Most IC comparators have been built and specified for high-speed digital system use. Many applications exist for a lower speed comparator. Again, starting with the single power supply differential input circuit of Figure 16 an interesting comparator results if only one additional transistor is added as shown in Figure 23. The added transistor, Q7,

provides the output simply as access to the collector of this device. This allows directly ORing the outputs and provides additional overall voltage gain to be obtained if a large valued external load impedance is used. This basic circuit provides an output current for an input difference voltage. As only 3 pins are needed for each comparator, 4 independent comparator circuits can be placed in a 14-pin package. The performance characteristics of this comparator are listed in Table III. This basic circuit is useful to compare, for example, voltage analogs of temperature, velocity, or acceleration with dc reference voltages and to provide a digital-type of output signal when the measured parameter exceeds the reference value.

TABLE III. Performance Characteristics of the Comparator (LM339)

Voltage Gain, $R_L = 15 k\Omega$	200,000
Input Common Mode Voltage Range ($V_{CC} = +15 V_{DC}$)	0V to 13V
Dc Input Bias Current	35 nA
Input Offset Voltage	3.0 mV
Output Current Sink Capability	6.0 mA
Power Supply Voltage Range	3.0V to 36V
Bias Current/Comparator	0.2 mA

A few basic comparator applications are shown in Figure 24. An important circuit is the ground referenced thermocouple sensor which is shown in Figure 24a. The ability to range the input common mode voltage to ground is needed for this application. Two comparators can be connected as a limit comparator, Figure 24b, where the lamp is "ON" when the input voltage is between the high and the low reference voltage levels. All four comparators can be used as a time delay generator as shown in Figure 24c. Here, the first comparator is used to reset the timing capacitor C1, and as the voltage across this capacitor exponentially rises, the other three comparators will fire in sequence to provide three time delayed outputs. Hysteresis can be added to a basic comparator as shown in Figure 24d. The 10M feedback resistor to the (+) input establishes the amount of hysteresis.

The relatively fast response of this comparator (compared with an internally compensated op amp) allows many digital type of application circuits. For example, the comparator can operate from a +5.0 V_{DC} power supply and drive a TTL gate as shown in Figure 25a. The low power drain of this comparator makes it an ideal component for CMOS systems, see Figure 25b. "AND" and "OR" gates can be built as shown in Figure 25c. The fast rise and fall times of the comparator can be used to advantage in the high frequency square-wave oscillator circuit of Figure 25d and the crystal controlled oscillator of Figure 25e.

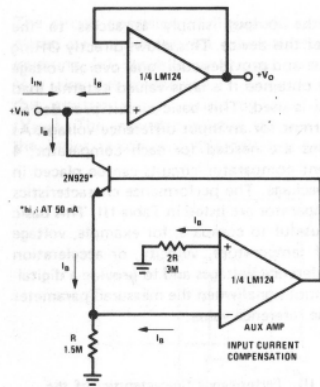
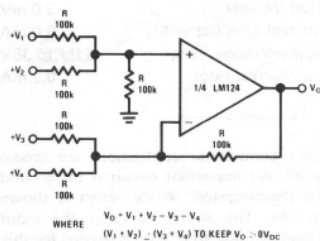
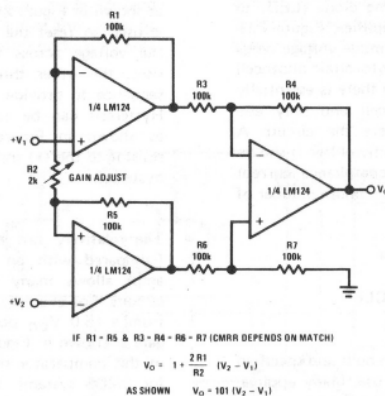


FIGURE 19. Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



(A) DC Summing Amplifier ($V_{IN'S} \geq 0$ VDC and $V_O \geq 0$ VDC)



(C) High Input Z Adjustable-Gain DC Instrumentation Amplifier

FIGURE 21. Some Applications of the True Differential Input Quad

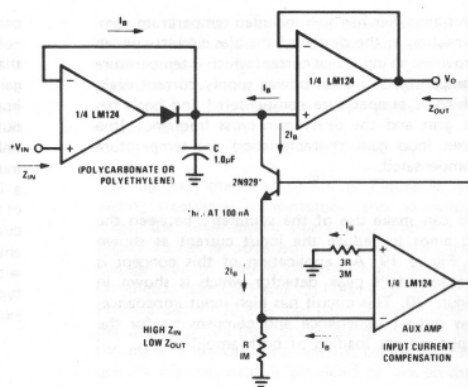
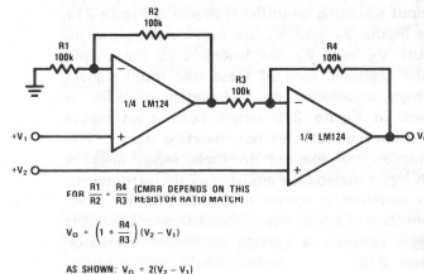
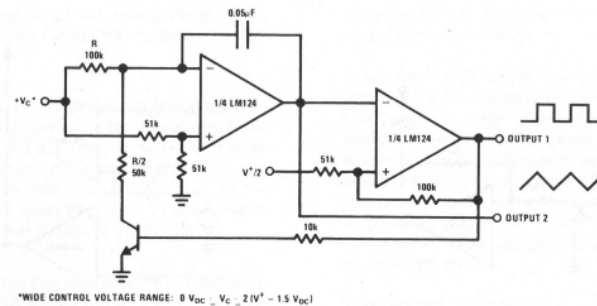


FIGURE 20. Low Drift Peak Detector

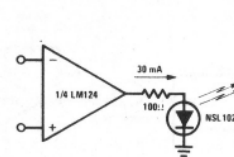


(B) High Input Z, DC Differential Amplifier

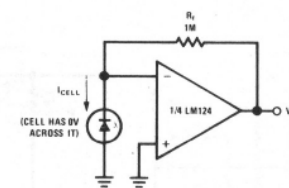


(D) Voltage Controlled Oscillator (VCO)

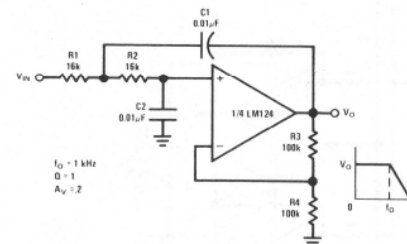
FIGURE 21. Some Applications of the True Differential Input Quad (con't)



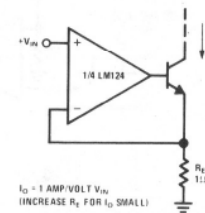
(A) LED Driver



(B) Photovoltaic-Photocell Amplifier



(C) DC Coupled Low-Pass RC Active Filter



(D) High Compliance Current Sink

FIGURE 22. Some Additional Applications of the Quad Op Amp

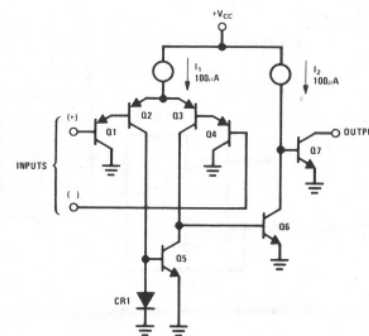
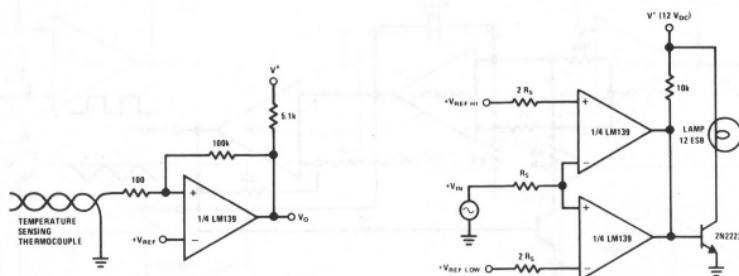
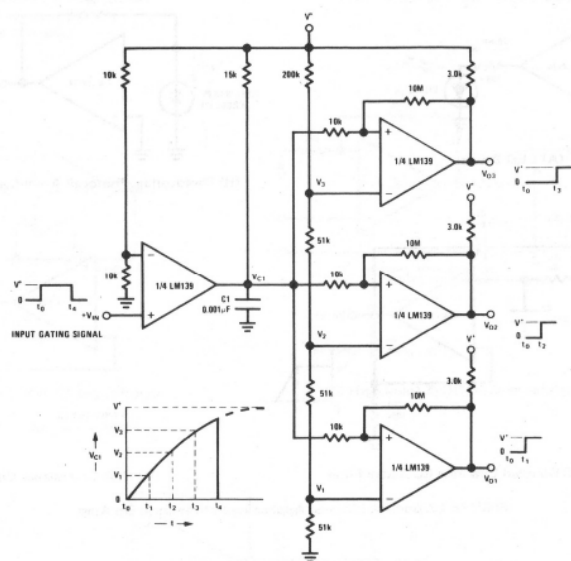


FIGURE 23. Single Supply Comparator

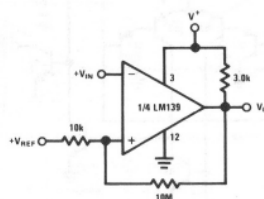


(A) Ground Referenced Thermocouple in Single Supply System

(B) Limit Comparator



(C) Time Delay Generator



(D) Comparator With Hysteresis

FIGURE 24. Comparator Applications

Finally, the outputs of the comparators can be directly connected, Figure 25f, to obtain an OR function.

Some unusual comparator applications are shown in Figure 26. If a frequency compensation capacitor is added directly across the output of a comparator, a low frequency op amp, (Figure 26a), can be obtained. The fast rise and fall times of the comparator have again been used to advantage in the pulse generator circuit of Figure 26b.

The voltage controlled oscillator (V_{CO}) circuit of Figure 26c is making use of many of the features of the comparator. A dual slope integrator, a Schmitt trigger and a clamp function are interconnected to provide the V_{CO} . The transducer

amplifier of Figure 26d can also be used as a tape reader for digital systems.

These new single supply quads have been rapidly accepted by the industry and are finding application in a wide range of new linear systems. The flexibility which is now made available to the automotive system designers by these "building blocks" is allowing a number of automotive control systems to be realized within a shorter design cycle and provides the ability to accommodate last minute system changes without a complete IC re-design phase.

This concept of single-supply linear quads is one of the fastest growing areas in linear integrated circuits and has allowed a new generation of lower cost single supply linear systems.

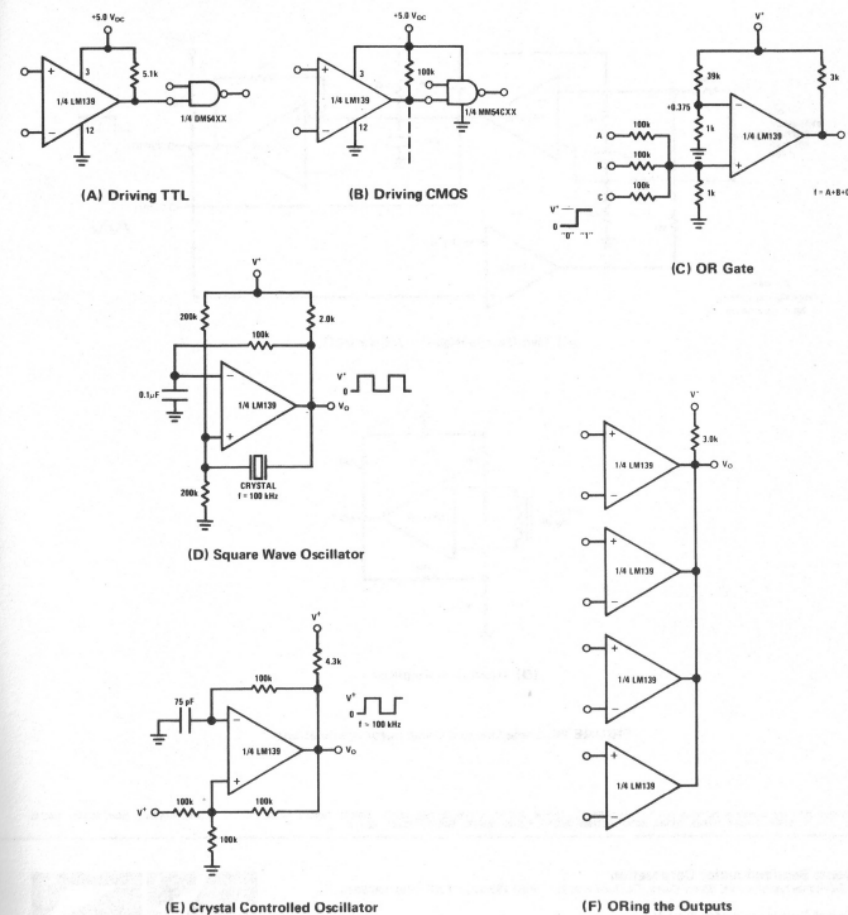
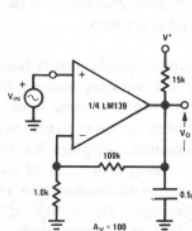
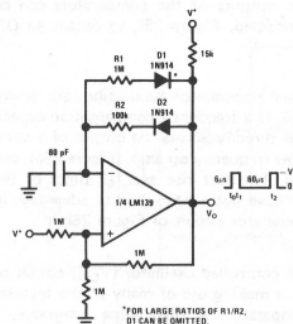


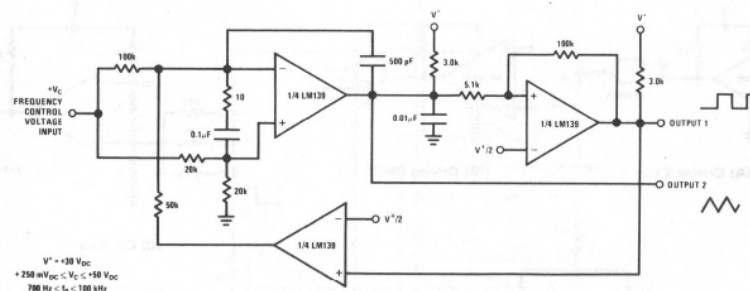
FIGURE 25. Some Digital Applications



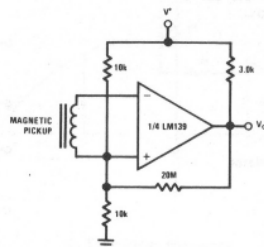
(A) Low Frequency Operational Amplifier



(B) Pulse Generator



(C) Two-Decade High-Frequency VCO



(D) Transducer Amplifier

FIGURE 26. Some Unusual Comparator Applications

Manufactured under one or more of the following U.S. patents: 3083252, 3180758, 3231707, 3263356, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440498, 3518750, 3519897, 3557431, 3560765, 3566218, 3571630, 3575609, 3579059, 3593069, 3597640, 3607469, 3617859, 3631312, 3633052, 3638131, 3648071, 3651565, 3693248.

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NOTES

NOTES

LINEAR QUAD CONTEST

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RULES

1. Prizes awarded for the best utilization of all four devices in a linear quad.
2. Signed entry blank must accompany all entries.
3. Contest runs from August 20 to October 31, 1973. All entries must be postmarked by October 31, 1973.
4. Entries must be conceived and written by entrant, and must not have been published. (Limited distribution of House Organs excepted).
5. Exclusive publishing rights remain with National Semiconductor.
6. Employees of National Semiconductor and Cahners Publishing are not eligible to enter this contest.
7. Decisions by judges are final. In case of duplicate entries, entry with the earliest postmark wins.
8. Contestant agrees that the design submitted may be published by National Semiconductor and Cahners Publishing and shall become the sole property of National Semiconductor.

I hereby submit my idea(s) for the National Linear Quad contest and agree to abide by all rules stated above.

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